Wairarapa Valley groundwater resource investigation

Framework for conjunctive water management

greater WELLINGTON
REGIONAL COUNCIL
Te Pane Matua Taiao

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Executive summary

This report is a revised version of the Hughes and Gyopari (2011) report *Wairarapa Valley groundwater resource investigation: Proposed framework for conjunctive water management*. The nature of the revisions is described in the report Introduction.

The groundwater resources of the Wairarapa Valley have a high environmental and cultural value in sustaining freshwater ecosystems and an important social and economic value in meeting water demands for domestic, municipal, agricultural and industrial purposes. Rapidly growing pressure on the water resources of the Wairarapa Valley over the past decade led Greater Wellington Regional Council to initiate a comprehensive investigation of groundwater in the Wairarapa Valley to re-assess the sustainable yields of aquifers in the valley. This report, which forms Phase 3 of the Wairarapa Valley groundwater resource investigation, focuses on the development of a water allocation methodology that will ensure both groundwater and surface water resources are sustainably managed. It follows a technical analysis of the groundwater environments of the Wairarapa Valley and the development of three sub-regional numerical groundwater flow models suitable for evaluating sustainable aquifer yields.

Development of a sustainable groundwater allocation methodology for the Wairarapa Valley has been approached from a conjunctive water management perspective. There are two fundamental components to the approach proposed:

1. Management of those groundwater abstractions that have a direct or immediate effect on the surface water environment through application of pumping controls based on minimum flows established for hydraulically connected surface waters; and
2. Establishment of fixed allocation volumes for individual groundwater management units that recognise that groundwater abstraction may cumulatively cause a reduction in river or stream baseflow. These allocation limits will apply where groundwater abstraction does not result in an immediate or direct streamflow depletion effect.

In order to implement these objectives, a three-tier management approach is proposed to establish a framework for managing groundwater abstraction according to the potential impact on surface water. The concept of '*hydraulic connectivity*' is utilised to differentiate those groundwater takes which have a direct and immediate effect on surface water from those where there is a considerable lag between pumping and resulting effects on surface water.

In areas of the hydrogeological system where there is a direct hydraulic connection with surface water (identified as *Category A*) it is proposed that groundwater abstraction will effectively be managed as equivalent surface water abstraction. In those areas where there is a moderate to low hydraulic connection (*Category C*), groundwater abstraction will be managed in terms of a groundwater allocation volume established to limit the maximum cumulative depletion of baseflow at a catchment (or sub-catchment) scale. In intervening areas (*Category B*), it is proposed to manage groundwater abstraction through a combination of temporal pumping restrictions (i.e. minimum flow cut-offs) and determine groundwater allocation on the basis of local hydrogeological conditions and abstraction rates.

Overall, the proposed framework effectively establishes a three-dimensional framework for the management of the cumulative effects of groundwater abstraction on surface water based on geographic location and depth criteria which vary according to the local hydrogeological environment and resulting connectivity between surface and groundwater resources.

Contents

1. Introduction

The groundwater resources of the Wairarapa Valley have a high environmental and cultural value in sustaining freshwater ecosystems and an important social and economic value in meeting water demands for domestic, municipal, agricultural and industrial purposes. Rapidly growing pressure on the water resources of the Wairarapa Valley over the past decade has required Greater Wellington Regional Council (GWRC) to review its current water allocation methodology to ensure both groundwater and surface water resources continue to be sustainably managed into the future.

At the current time approximately half of the 29 groundwater zones in the Wairarapa Valley defined in GWRC's current Regional Freshwater Plan (RFP, WRC 1999) are allocated at levels in excess of 60% of their calculated '*safe yields*'[1]. In general, the most highly allocated zones contain the most productive aquifers in the Wairarapa Valley which are typically located along the riparian margins of the major river systems.

Due to the nature of its geology and geomorphology, the Wairarapa Valley is essentially a closed hydrogeological system in which outflow occurs predominantly as discharge into the Ruamahanga River system or Lake Wairarapa at the downstream basin margin[2]. As a consequence, groundwater abstraction has the potential to contribute to a cumulative reduction in basin outflow, although the timing and magnitude of effects are highly dependent on the hydraulic connectivity between source aquifer(s) and the surface water environment.

The RFP has separate policies for allocation of surface and groundwater resources. This lack of integration between management of groundwater and surface water allocation results in the potential for groundwater abstraction to result in stream depletion in hydraulically connected rivers and streams (particularly during periods of low flow) which is not accounted for within existing surface water allocation.

One consequence of the failure to account for potential effects of groundwater abstraction on surface water is a situation referred to as "double accounting". This can occur where groundwater that may otherwise contribute to surface water baseflow discharge is allocated for abstraction from hydraulically connected aquifers. If the consequent reduction in baseflow is not recognised in the allocation of surface waters, then the potential exists to essentially allocate the same water twice: once from the hydraulically connected groundwater system and again from surface water receiving baseflow discharge from the aquifer.

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1 Safe yield is the term used in the RFP to define the sustainable allocation limit calculated for each groundwater management zone. However, the definition of safe yield has since evolved significantly such that many of the current RPF 'safe yields' are no-longer considered sustainable.

2 Losses from the basin also occur via direct evaporation from rivers and lakes and evapotranspiration where vegetation directly accesses the underlying water table.

1.1 Background

In 2005 GWRC commenced a staged investigation to improve definition of the hydrogeology of the Wairarapa Valley and develop a framework for future sustainable management of the groundwater resource. This report outlines the final management recommendations developed from the preceding technical investigations. The phases of the investigation are briefly outlined below.

Phase 1 – Regional conceptual and numerical modelling of the Wairarapa Valley groundwater basin

This preliminary phase of the investigation, reported by Jones and Gyopari (2006), consolidated existing knowledge of the hydrogeology of the Wairarapa Valley to provide a regional-scale evaluation of the groundwater resource. The investigation was largely based on existing information and resulted in a revised geological model. This phase of the investigation culminated with the development of a regional conceptual hydrogeological model and a 'bulked' steady-state numerical model to test conceptualisation and identify additional information requirements. Phase 1 also identified three sub-catchments (Upper, Middle and Lower Valley) that essentially set the scene for the comprehensive Phase 2 investigations.

Phase 2 – Detailed sub-regional resource analysis and modelling

The Phase 2 investigation focussed on development of transient groundwater flow models to provide a management tool to assist sustainable management of the groundwater resource. Investigations undertaken for this phase of the project included field studies to address key information gaps identified by the Phase 1 investigation, as well as detailed analysis and quantification of aquifer recharge processes, groundwater abstraction and hydrochemistry. The primary output from this phase of the investigation was the development of three separate groundwater flow models for the Upper, Middle and Lower Valley sub-catchments (documented in Gyopari and McAlister 2010a, 2010b and 2010c respectively).

Phase 3 – Groundwater resource sustainability assessment

The third phase of the investigation was the application of the outputs from the first two phases of the project to the development of a proposed management framework to enable sustainable management of the groundwater resources of the Wairarapa Valley (culminating in a report by Hughes and Gyopari (2011)). In particular, this work utilised both the conceptual and numerical models developed for the Phase 2 investigations to develop options for sustainable groundwater allocation limits as well as the management of stream depletion effects resulting from groundwater abstraction.

Phase 4 – Revised groundwater resource sustainability assessment

Since the original Hughes and Gyopari (2011) report, work has continued to refine some aspects of the allocation assessment. This current report is a revision of the Hughes and Gyopari (2011) report and is intended to supercede that original version. The revisions are focused on the following areas:

A. In the earlier Hughes and Gyopari (2011) report, several options were provided for allocating water in each groundwater management zone (Tables 4.4−4.6 and Appendices D−F). In this report, options remain listed but one option for each zone is now also **recommended**. These recommendations are based on a range of factors − that include existing level of allocation, perceived state of the water resources and river and stream values in the zone and water availability – that are discussed more fully in Appendices D−F

B. A discussion about uncertainty and error has been introduced in this report (Appendix H). The discussion covers both likely errors associated with the numerical modelling that underpins the allocation assessment and more general uncertainties and assumptions relating to the approach taken. Also incorporated is reference to an independent parameter uncertainty analysis commissioned by GWRC and completed since the Hughes and Gyopari (2011) report was issued. This analysis focused on determining the reliability of selected predictive simulations that subsequently formed the basis of groundwater allocation management decisions.

C. Since the original Hughes and Gyopari (2011) report was issued, a broad independent peer review of the overall conjunctive framework has been completed (for the Wairarapa Valley, Hutt Valley and other areas). Where appropriate, responses to peer review have been incorporated in the revised content of this report.

D. A number of recommendations made in the Hughes and Gyopari (2011) report have been advanced or implemented. Discussion of these initiatives is provided in section 6 of this report.

Overall, the revisions in this report can be considered as refinements, clarifications and fuller discussion and justification for decisions taken. None of the revisions are considered to represent substantive changes from the Hughes and Gyopari (2011) report. The principles of the proposed conjunctive water management framework as presented in the Hughes and Gyopari (2011) report have not changed. Also, groundwater management zone boundaries and categories remain unchanged.

1.2 Report objectives

The overall objective of the report is to recommend an approach for the sustainable management of the groundwater resources of the Wairarapa Valley that takes into account potential effects of groundwater abstraction on surface water bodies. As the main focus of the report is on management options that may be considered as part of future policy development, the report is primarily intended for a technical/policy audience.

To provide context for the management options outlined, more general readers are directed to Appendix A and Appendix B which provide an introduction to general concepts relating to management of groundwater/surface water interaction and provide an overview of the nature and extent of groundwater/surface water interaction in the Wairarapa Valley (respectively).

1.3 Report structure

This report provides recommendations for the establishment of a framework for managing groundwater allocation in the Wairarapa Valley that considers both the sustainability of groundwater abstraction and cumulative effects on hydraulically connected surface water bodies. The report comprises the following sections:

- Section 2 – *Management framework*: A conceptual outline of the framework for the conjunctive management of groundwater and surface water in the Wairarapa Valley.
- Section 3 – *Management of direct stream depletion effects*: The classification and management of groundwater takes which have a direct effect on stream flow.
- Section 4 – *Management of the cumulative effects of groundwater abstraction on river baseflow*: The rationalisation of existing groundwater management zones in the Wairarapa Valley including options for volumetric groundwater allocation limits.
- Section 5 – *Implications for monitoring and management*: A review of potential implications for monitoring and management of groundwater and surface water resources in the Wairarapa Valley that result from adopting the conjunctive water management framework.
- Section 6 – *Summary and conclusions*

Appendices to the report:

- Appendix A – *Technical and policy background*: A description of some of the basic concepts relating to management of groundwater/surface water interaction.
- Appendix B – *Groundwater - surface water interaction in the Wairarapa Valley*: Description of the nature of groundwater and surface water interaction in the Wairarapa Valley.
- Appendix C – *Quantifying groundwater abstraction on stream flow*: Application of the Upper, Middle and Lower catchment groundwater models to determine the spatial (and depth) variations in potential stream depletion effects across the Wairarapa Valley.
- Appendix D – *Upper Valley groundwater allocation*: Details of numerical modelling undertaken to determine potential groundwater allocation limits in the Upper Valley catchment.
- Appendix E – *Middle Valley groundwater allocation*: Details of numerical modelling undertaken to determine potential groundwater allocation limits in the Middle Valley catchment.

- Appendix F – *Lower Valley groundwater allocation*: Details of numerical modelling undertaken to determine potential groundwater allocation limits in the Lower Valley catchment.

- Appendix G – A3 scale maps of the proposed hydraulic connection categories for the Upper, Middle and Lower valleys.

- Appendix H – *Uncertainty:* A discussion about numerical model uncertainty and other sources of uncertainty relating to the conjunctive water management framework.

2. Management framework

The groundwater resources of the Wairarapa Valley form an integral component of the overall hydrological cycle and have a significant role in sustaining freshwater ecosystems in riverine and wetland habitats. Significant use is also made of the groundwater resource for domestic, municipal, industrial and irrigation water supplies. Managing potential conflicts between maintenance of environmental values associated with the groundwater resource (including hydraulically connected surface water) and the potential social and economic benefits arising from consumptive use of water presents a major resource management challenge.

As described in greater detail in Appendix B, groundwater and surface water resources throughout the Wairarapa Valley typically exhibit a high degree of connectivity, particularly within the recent gravel deposits along the riparian margins of the main river systems. Due to the nature and extent of interaction between groundwater and surface water, the groundwater resource comprises a major component of the overall hydrological system. Managing both localised and cumulative effects of groundwater abstraction on hydraulically connected surface waters is therefore a key component of a framework to enable integrated management of surface and groundwater allocation to ensure environmental values can be maintained at or above thresholds established by the community through the Regional Plan review process.

2.1 Groundwater management under the current RFP

The current Regional Freshwater Plan, or RFP, (Wellington Regional Council, 1999) essentially manages groundwater and surface water as separate entities and does not explicitly consider the impacts of groundwater abstraction on surface water on a catchment or sub-catchment basis. However, there are provisions for addressing the direct effects of groundwater abstraction from some riparian aquifers on adjacent connected surface waters where this is considered appropriate. The RFP designates a number of groundwater management zones for the Wairarapa Valley (Appendices D−F) with associated 'safe yields' based principally upon recharge and/or throughflow calculation. The interconnection between zones or the influence of connected surface waters is generally not considered.

The concept of 'safe yield' adopted in the current RFP calculations assumed that all aquifer inflow was essentially available for allocation. Current sustainable aquifer management practice however strongly advocates that only a portion of aquifer recharge should be utilised to prevent adversely affecting groundwater dependent ecosystems which are sustained by aquifer discharge. Allocation volumes are therefore balanced against acceptable effects on connected freshwater ecosystems which are sustained by groundwater discharge. This is the basis of the conjunctive water management framework described in this report. Many of the groundwater zone 'safe yields' in the current RFP are not therefore considered 'safe' or sustainable and need to be revised on the basis of current sustainable management practices which must take into consideration the connected surface water environment and the cumulative effects of groundwater abstraction on a catchment and sub-catchment level.

2.2 Conjunctive water management

Recognising that surface water and groundwater resources within a catchment are fundamentally linked means that management of these resources needs to be undertaken in a coordinated way. Such an integrated approach has been termed *conjunctive water management*.

In its simplest application, the term conjunctive water management describes '*the management of hydraulically connected surface water and groundwater resources in a coordinated way, such that the total benefits of integrated management exceed the sum of the benefits that would result from independent management of the surface and groundwater components'* (Sahuquillo and Lluria 2003).

In this report, the term conjunctive water management is used to describe a framework for the management of groundwater allocation in the Wairarapa Valley which recognises the hydraulic connection between groundwater and surface water and enables consumptive groundwater use in a manner that is consistent with environmental flow and water levels established for hydraulically connected surface water resources.

Brodie et al. (2007) outlined general principles for the application of conjunctive water management in the Australian context which include:

1. Where physically connected, surface water and groundwater should be managed as one resource;

2. Water management regimes should assume connectivity between surface water and groundwater unless proven otherwise;

3. Water users (both surface and groundwater) should be treated equitably.

These principles have been utilised to guide development of the suggested framework for conjunctive management for the Wairarapa Valley outlined in this report.

Brodie et al. (2007) also proposed the framework for conjunctive water management shown in Figure 2.1. This framework incorporates the principle of adaptive management which enables the regulatory response to a particular natural resource management issue to incorporate improved understanding of the dynamic response of the physical environment to development pressures and adapt to changing management objectives over time.

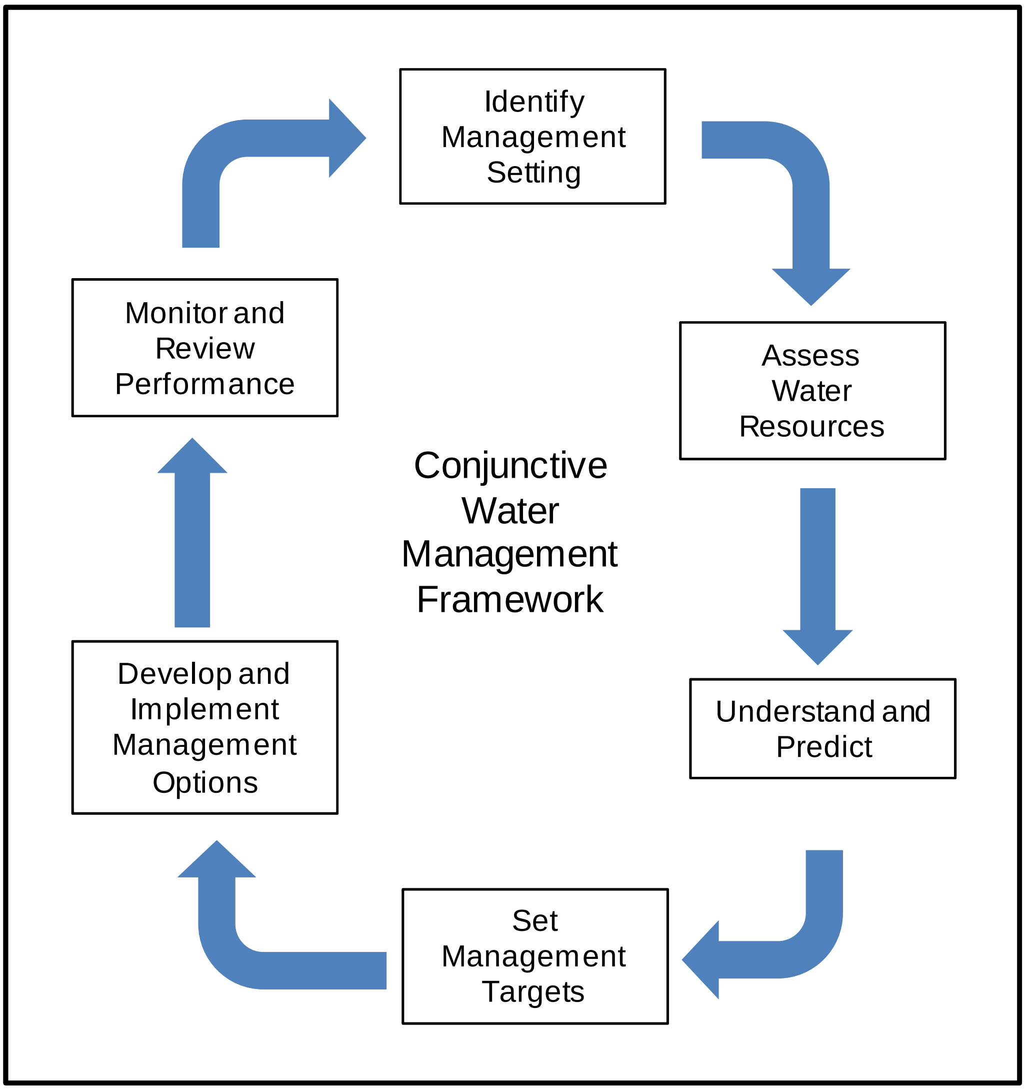

Figure 2.1: A framework for conjunctive water management (from Brodie et al. 2007)

Key elements of the process for successful development and implementation of a framework for conjunctive water management include:

- Development of a good conceptual understanding of the interaction between groundwater and surface water in a catchment;
- Development of a consistent, technically sound approach to the management of groundwater-surface water connectivity;
- Application of numerical models and other predictive tools to improve understanding of the dynamic behaviour of the resource, establish resource management targets and evaluate future management options;
- Co-ordinated monitoring of groundwater and surface water resources to characterise dynamic behaviour of the resource in response to development pressure and ensure management targets are being achieved.

2.3 Applying conjunctive water management to the Wairarapa Valley

Following the principles outlined in the previous section, Figure 2.2 provides a schematic illustration of the application of the conjunctive water management concept to the development of a framework for managing groundwater allocation in the Wairarapa Valley.

Development of the management framework follows on from the extensive data collection and analysis undertaken for the Phase 1 and Phase 2 components of the Wairarapa Valley groundwater resource investigation. In particular, the conceptual hydrogeological model developed from these investigations was utilised to refine understanding of the potential nature of groundwater / surface water interaction across the range of hydrogeological environments present in the Wairarapa Valley and to develop a framework for management of 'direct' stream depletion effects.

Numerical groundwater flow models were then used to test a range of scenarios designed to characterise the hydraulic connectivity between groundwater and surface water over a range of spatial (and depth) scales and re-evaluate the spatial units (water management zones) utilised to manage groundwater allocation. Where hydraulic connectivity is not sufficient to enable active management (i.e. mitigation) of potential stream depletion effects during periods of low flow, scenario modelling was utilised to identify options for groundwater allocation limits intended to manage cumulative effects of groundwater abstraction on baseflow at a regional scale.

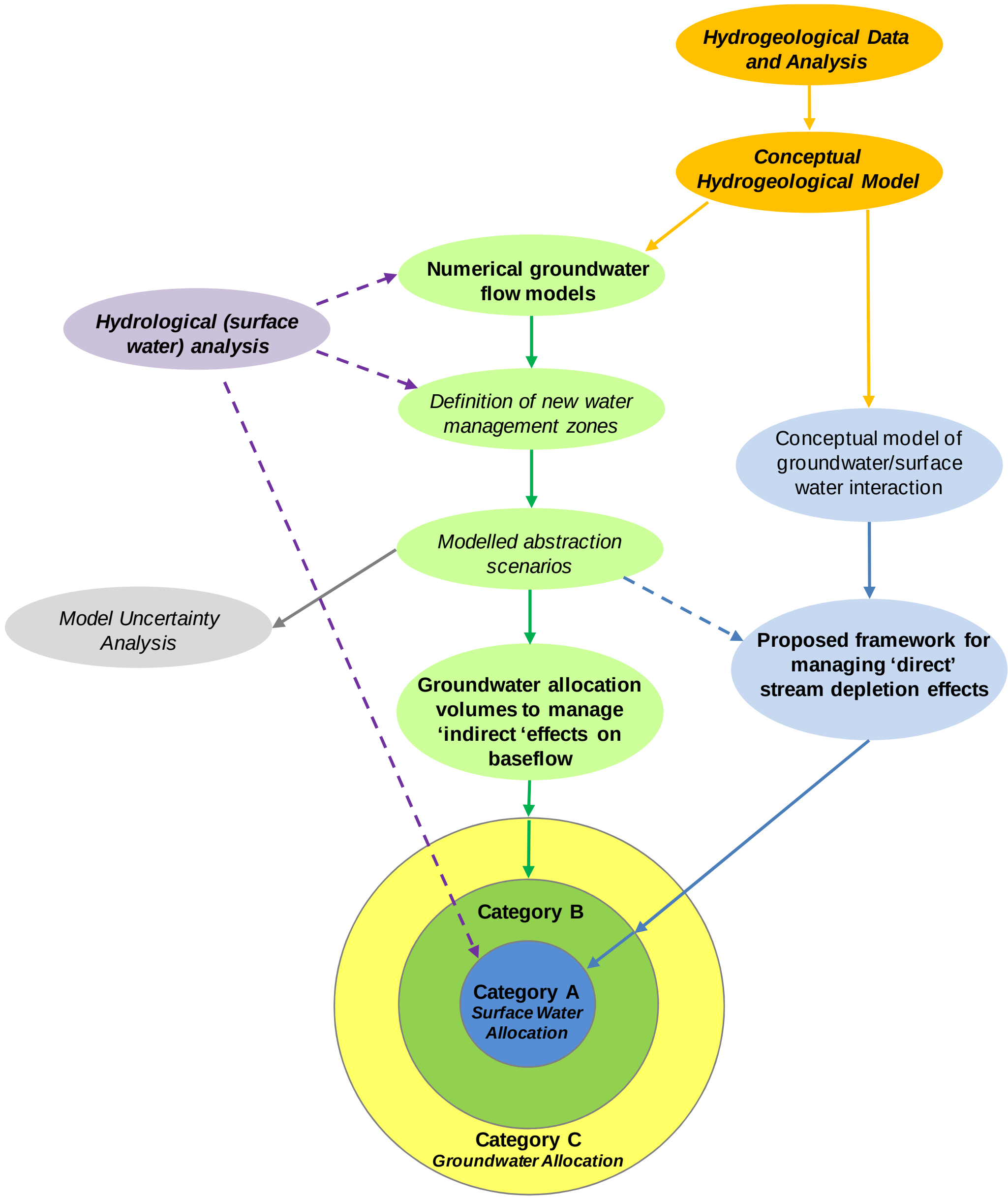

Figure 2.2: Conceptual outline of the development of a framework for conjunctive water management in the Wairarapa Valley

Given the significant reliance on groundwater modelling, analysis of model uncertainty is important to validate the management approach. At the time of writing, this uncertainty analysis was still in progress for the three groundwater models (Upper, Middle and Lower Valley) developed for the Phase 2 investigations.

2.4 Management approach

As described in Appendix B, virtually all groundwater in the Wairarapa Valley is hydraulically connected to surface water to some degree. As a consequence, groundwater abstraction has the potential to impact on surface water flows either as a result of localised (direct) stream depletion effects or through indirect effects on baseflow at a catchment scale. However, application of analytical and numerical modelling detailed in Appendix C shows that the exact magnitude and timing of effects on surface water resulting from groundwater abstraction varies considerably between individual hydrogeological environments. As a result, an effective management framework has to recognise and provide for the range of potential effects on hydraulically connected surface water resulting from groundwater abstraction across a range of hydrogeological settings.

This report outlines a conjunctive approach to management of the effects of groundwater abstraction on hydraulically connected surface water in the Wairarapa Valley that provides for:

1. Active management of those groundwater abstractions which have a direct or immediate effect on the surface water environment and can be effectively mitigated by the application of management controls (such as minimum flow cut-offs); and

2. Designation of spatially defined management units which are assigned volumetric allocation limits that take account of the potential cumulative effects of groundwater abstraction on river or stream baseflow at a catchment scale.

A three-tier management framework manages groundwater abstraction according to the potential to impact on surface water. The framework allows differentiation between those groundwater takes which have a direct and immediate effect on surface water, from those where there may be considerable lag between pumping and resulting effects, based on three nominal categories of hydraulic connection. This effectively establishes a three-dimensional framework for the management of groundwater abstraction based on geographic location and depth criteria.

The hydraulic connection categories proposed are outlined below.

Category A: Direct hydraulic connectivity

Category A includes areas of the hydrogeological system which exhibit direct connectivity with surface water. Stream depletion effects occur shortly following the commencement of groundwater abstraction, rapidly increase to a level close to the overall pumping rate and dissipate quickly once pumping stops. As a consequence, a high proportion of the overall volume of groundwater pumped effectively represents induced flow loss from local surface waterways. Due to the immediacy of impact, groundwater abstraction from Category A aquifers can be considered analogous to direct surface water abstraction and managed in terms of the environmental flow and water level regimes established for hydraulically connected surface waterbodies.

Category B: High hydraulic connectivity

Category B includes those areas of the hydrogeological system where groundwater abstraction may potentially result in significant impacts on surface water but where pumping regulation does not always provide an effective option for mitigating direct stream depletion effects. Category B represents the transition between indirect and direct stream depletion effects where it may be appropriate to manage groundwater takes in terms of either surface water or groundwater allocation depending on localised factors (e.g. local aquifer hydraulic parameters, abstraction rate and location of pumping with respect to surface waterbodies).

Category C: Moderate to low hydraulic connectivity

Category C covers those areas of the hydrogeological system where groundwater abstraction may contribute to an overall reduction in baseflow discharge at a catchment scale but where active regulation of pumping does not provide effective mitigation of potential effects on surface water. Cumulatively, these takes are more appropriately managed at a catchment or sub-catchment scale through the establishment of volumetric abstraction limits.

The following sections of the report outline the development and application of the conjunctive water management framework for the Wairarapa Valley.

Appendix C provides an overview of the numerical and analytical model analysis undertaken to characterise the nature and extent of groundwater/surface water interaction across a range of hydrogeological settings in the Wairarapa Valley. Based on this analysis, Section 3 outlines the approach for managing direct stream depletion effects in Category A and B aquifers including the spatial (and depth) distribution of the proposed hydraulic connection categories. Section 4 then describes the spatial units (*water management zones*) for the management of cumulative effects of groundwater abstraction on surface water from Category B and C areas which are not subject to pumping controls (minimum flow restrictions). Details of the numerical model analysis undertaken to define the groundwater individual water management zones and determine the spatial (and depth) extent of the Category A, B and C areas are provided in Appendices D, E and F.

3. Managing direct stream depletion effects

In the past, surface and groundwater resources in the Wellington region have been managed separately due to their different modes of occurrence, assessment and development. Although there has been increasing recognition of the interconnection between these resources in recent years, there has been limited formalisation of approaches to more closely integrate management of surface water and groundwater.

As described in the preceding section, the framework for conjunctive water management in the Wairarapa Valley establishes three categories of hydraulic connection. This section of the report addresses the management of *direct stream depletion* effects (as defined in Appendix A) for groundwater takes located in areas classified Category A (direct hydraulic connection) and Category B (high hydraulic connection).

The initial concept for the management of direct stream depletion effects was to establish a generic framework which would apply uniformly to the entire Wairarapa Valley. However, based on a review of available hydrogeological information and outputs from model scenarios, it became apparent that it was impractical to develop a generic approach which would fit the wide range of hydrogeological environments identified. As a result, this section of the report outlines the criteria utilised to define the spatial and depth extent of the proposed Category A and B hydraulic connectivity areas based on outputs from the numerical modelling analysis outlined in (Appendices D to F) and outlines the approach for classification and management of direct stream depletion effects.

As described in greater detail in Appendix A, the magnitude and timing of stream depletion effects resulting from groundwater abstraction depends on a wide range of factors which include the hydraulic properties of the aquifer system as well as the location and rate of pumping. Due to the buffer provided by aquifer storage, stream depletion effects tend to be diffuse, lag changes in abstraction rate and occur at a rate lower than the overall rate of groundwater abstraction. As a consequence, there are no clear thresholds between insignificant and significant effects and it is necessary to define arbitrary criteria to determine those groundwater takes that may have a significant effect on hydraulically connected surface water and may be amenable to mitigation by application of pumping controls. It is noted that although the criteria for managing direct stream effects in the following section are largely arbitrary, they are consistent with existing management approaches adopted by other regional councils outlined in Appendix A.3.

3.1 Category A – Direct connectivity

3.1.1 Definition

The shallow, highly permeable gravel aquifers – often called Q1 aquifers[3] in this report – which occur along the riparian margins of the main river systems

[3] Q1 is a geological unit name that describes the youngest aquifer material deposits in the Wairarapa Valley. See Table B.1 in Appendix B for a full list of geological units and descriptions.

in the Wairarapa Valley are classified as Category A aquifer systems. In these areas, both physical monitoring data and modelled pumping scenarios indicate a high degree of connectivity between the groundwater system and adjacent surface water resources. The Category A classification is also extended to include the groundwater catchments of the major spring-fed streams (e.g. the Greytown Springs, Stonestead and Poterau streams) to reflect the sensitivity of these environments to changes in flow induced by relatively small reductions in groundwater levels resulting from groundwater abstraction. The extent of the Category A classification is shown in Figure 3.6; a detailed description of the rationale applied to define the spatial extent of Category A in individual water management zones is outlined in Appendices D to F.

Figure 3.1 shows a representative stream depletion curve resulting from groundwater abstraction from a Category A aquifer over a nominal pumping period of 100 days[4] calculated using an analytical stream depletion model (Hunt 1999). The figure reflects the high degree of connectivity between groundwater and surface water and shows stream depletion effects develop rapidly once abstraction commences and dissipate quickly when abstraction ceases[5].

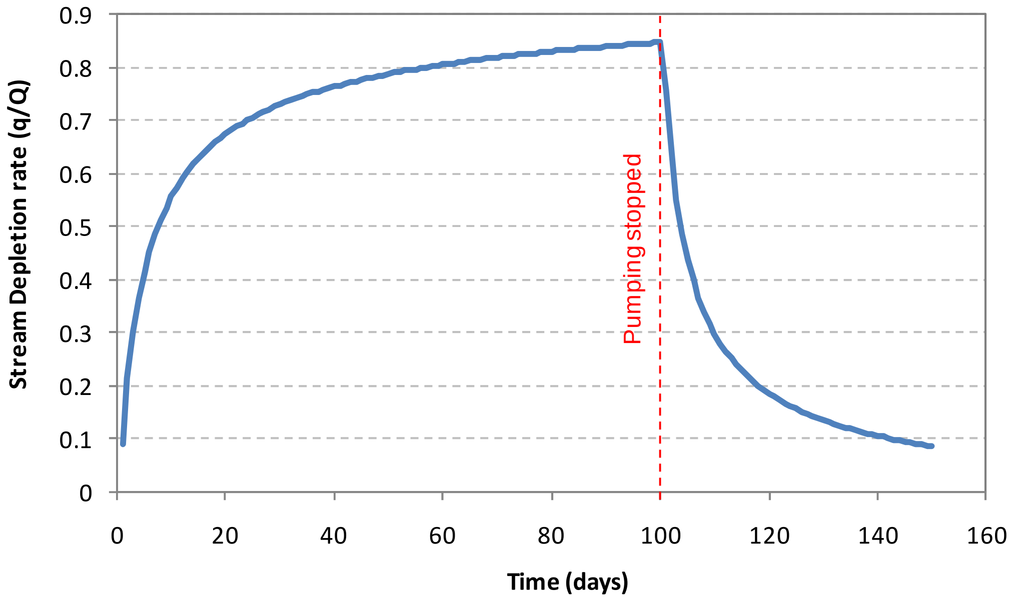

Figure 3.1: Representative modelled stream flow depletion curve resulting from groundwater abstraction in a Category A area

Figure 3.2 shows a corresponding plot of the relative contribution of groundwater storage and stream depletion to the overall volume of water abstracted[6]. In this case it is clearly evident that a bulk of groundwater pumped from the aquifer is derived from surface water with only a relatively minor contribution from groundwater storage.

4 The example shows illustrates a highly transmissive unconfined aquifer (T = 5,000 m^2/day, S = 0.1) where abstraction is located relatively close (500 metres) to a highly connected stream (streambed conductance = 100 m/day).

5 The potential rate of stream depletion is commonly referred to in terms of q/Q which is the ratio of direct stream depletion (q) to the overall pumping rate (Q). In this report the q/Q term is also used to define the degree of hydraulic connection between an individual pumped bore and a hydraulically connected surface waterway and is used as part of the criteria to determine how potential stream depletion from an individual groundwater take will be managed.

6 For the purposes of this illustration, assuming a nominal abstraction rate of 2,500 m^3/day for 100 days.

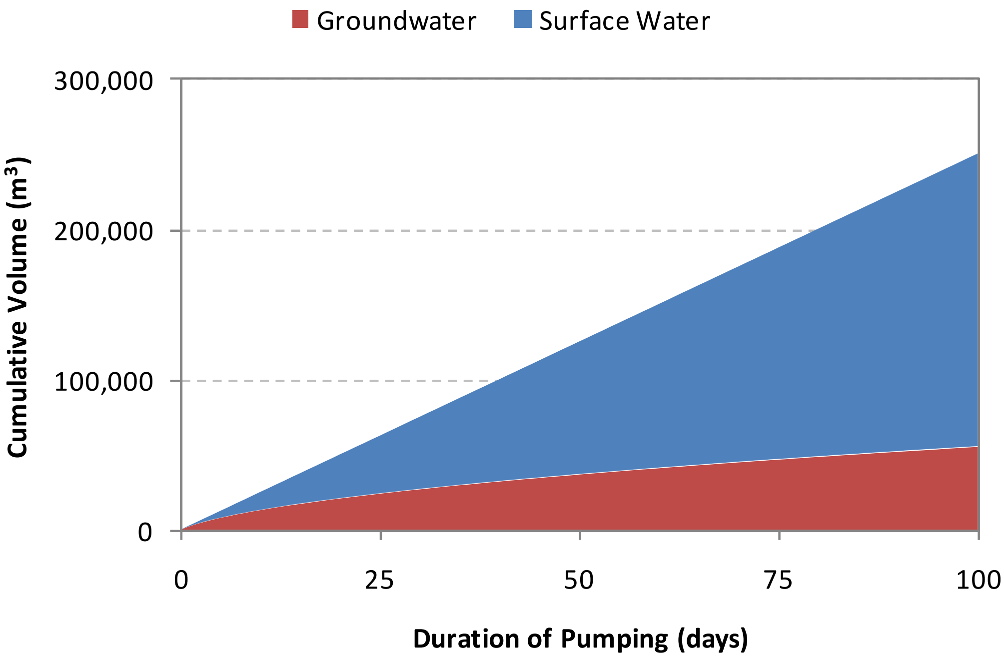

Figure 3.2: Relative contribution of groundwater storage and stream depletion for a representative groundwater take in a Category A area

Modelled pumping scenarios (summarised in Appendix C) demonstrate that, in Category A hydrogeological settings in the Wairarapa Valley, stream depletion effects quickly develop to a level close to the maximum instantaneous pumping rate once abstraction commences and dissipate rapidly when abstraction is ceased. The overall proportion of the water abstracted derived from aquifer storage is low and groundwater abstraction can reasonably be managed as an equivalent surface water take.

3.1.2 Application of Category A classification

Management controls apply to all groundwater takes which require resource consent within the nominated Category A areas. This would exclude permitted groundwater takes (e.g. stock and domestic uses under Section 14(b) of the Resource Management Act 1991 and takes below the permitted threshold, which is currently 20,000 L/day per property specified by Rule 7 of the RFP). However, exemptions or alternative pumping restrictions may apply to nominated water uses such as public water supplies.

3.1.3 Pumping regulation

Given the immediacy of the stream depletion response to groundwater abstraction and the significant contribution of surface water to the overall volume of groundwater abstraction, it is considered that groundwater abstraction from Category A areas can be reasonably managed as equivalent takes from hydraulically connected surface waterbodies. The rapid decline in stream depletion effects following the cessation of pumping illustrates the effectiveness of pumping regulation based on surface water minimum flows as a means to mitigate effects on surface water during periods of low flow.

Environmental flows and water levels established for hydraulically connected surface water[7] are applied to groundwater takes from Category A aquifers.

3.1.4 Allocation

As illustrated in Figure 3.2, groundwater abstracted from Category A aquifers is predominantly derived from surface water, so it is reasonable to include this abstraction within the allocation calculated for relevant hydraulically connected surface water bodies.

However, as there is some lag between changes in pumping rate and corresponding changes in the rate of stream depletion, allocation from Category A aquifers is counted as primary allocation from the relevant hydraulically connected surface water bodies based on the average weekly consented abstraction rate. Using the short-term (weekly) average abstraction rate rather than the instantaneous rate of take is intended to avoid over-estimation of the likely effect on surface water where groundwater is abstracted at a high rate on an intermittent basis.

3.1.5 Resource consent assessment requirements for takes in Category A aquifers

Given the inclusion of Category A groundwater takes within the primary allocation for hydraulically connected surface water, no specific assessment of potential stream depletion is required to support resource consent applications for Category A groundwater takes. However, assessment to determine localised effects of groundwater abstraction (e.g. interference effects) or impacts on surface water environments (e.g. effects on aquatic ecosystems/ecology) could be required to support individual resource consent applications.

Any resource consent application for groundwater abstraction from Category A aquifers which seeks to avoid pumping restriction or inclusion within surface water allocation limits (e.g. small scale, short duration or intermittent takes) could be required to demonstrate through a combination of physical evidence and modelling of long term impacts, that the potential cumulative effect on surface water is *de minimus*.

3.2 Category B – High connectivity

3.2.1 Definition

The Category B classification includes those hydrogeological settings where groundwater abstraction may result in significant effects on surface water depending on factors such as local aquifer hydraulic properties, the location of abstraction relative to surface waterways (particularly spring-fed streams and wetlands) and the overall rate (instantaneous and/or seasonal) of groundwater abstraction. As a consequence, the extent of the Category B classification varies both spatially and with depth reflecting the local hydrogeological characteristics of each water management zone.

7 Including minimum flows and flow allocation in rivers and streams as well as minimum water levels in hydraulically connected wetlands or lakes.

In areas defined as Category B, the hydraulic connectivity with surface water is typically lower than that observed in Category A areas. Physical evidence to characterise the degree of interaction between groundwater and surface water in Category B areas may be limited, necessitating a greater reliance on modelling to determine the magnitude and nature of potential stream depletion effects. Modelled abstraction scenarios outlined in Appendices C to F show that the magnitude of direct stream depletion typically declines away from the outer margin of Category A aquifers (Q1 gravels) depending on the hydraulic characteristics of the surrounding alluvial fan materials. As a result, groundwater abstraction along the outer margin of Category A aquifers (i.e. recent Q1 floodplain gravels) may warrant pumping regulation if sufficient hydraulic connection exists with surface water.

Category B also includes those areas of the alluvial fan (Q2) systems where hydraulically connected surface water bodies (spring-fed streams, seeps and wetlands) are present. These features may be affected by groundwater abstraction depending on the relative proximity and rate of abstraction as well as local hydrogeological characteristics. Rather than defining an arbitrary buffer around individual surface water features, the Category B classification allows the potential for stream depletion effects to be assessed through the resource consent process according to localised factors particular to individual groundwater takes.

The extent of the Category B classification is outlined in Section 3.3 with detailed description of the rationale applied to define the spatial extent of Category B in individual water management zones outlined in Appendices D to F.

Figure 3.3 shows a representative range of stream depletion curves expected in Category B aquifers over a nominal pumping period of 100 days calculated using the Hunt (1999) analytical method[8]. The curves demonstrate that as the degree of hydraulic connectivity (expressed in terms of q/Q, see footnote 3) decreases, the overall magnitude of stream depletion decreases and there is increased lag in response to variations in pumping rate (or cessation of pumping).

8 Calculated for a range of aquifer hydraulic properties to derive the nominated q/Q values of 0.7, 0.55 and 0.4.

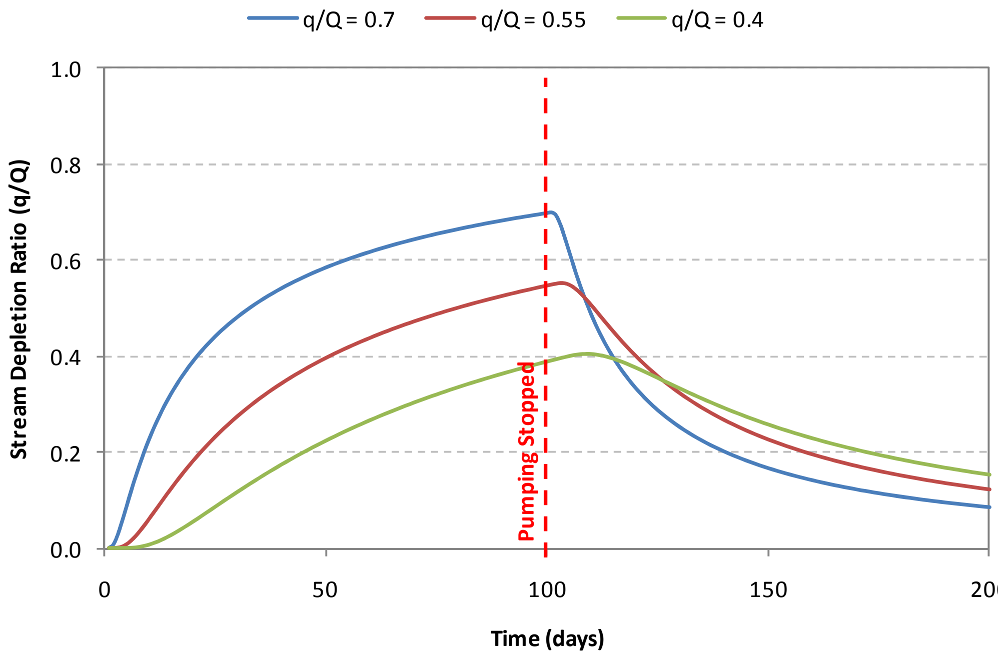

Figure 3.3: Stream depletion curves resulting from groundwater abstraction from a representative range of groundwater takes in a Category B area

Figure 3.4 shows a plot of the relative contribution of groundwater storage and stream depletion to the overall volume of groundwater pumped from a Category B aquifer (assuming q/Q=0.64 – see footnote 3 – and a nominal abstraction rate of 2,500 m^3/day). The graph illustrates that, while a majority of water pumped is derived from aquifer storage during the initial pumping period, stream depletion makes an increasing contribution to the total volume of abstraction over time, representing almost half of the total volume pumped after a period of 100 days in the example shown.

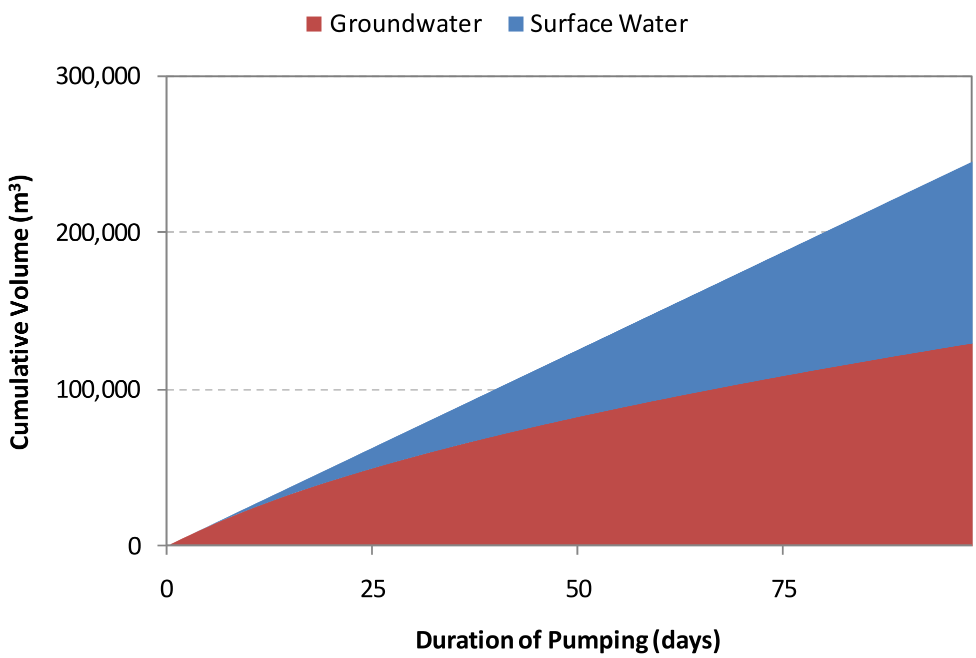

Figure 3.4: Relative contribution of groundwater storage and stream depletion for a representative groundwater take from a Category B groundwater area

3.2.2 Application of Category B classification

Due to the potential for takes from Category B aquifers to have a less direct effect on surface water than equivalent takes from Category A areas, groundwater takes with a weekly average abstraction rate less than an arbitrary minimum rate of 5 L/s within areas designated as Category B should be managed as solely as groundwater takes (i.e. included within the groundwater allocation limits outlined in Section 4). Takes above this threshold will be assessed in terms of the Category B hydraulic connection and volumetric assessment criteria.

The exemption for takes less than 5 L/s is a pragmatic means to ensure management of groundwater takes within Category B is focussed on those takes most likely to result in significant effects on surface water and avoid the requirement for stream depletion assessment to be undertaken where the rate of abstraction is relatively low. The potential cumulative effect of small takes will be managed in terms of the groundwater allocation for the relevant water management zone rather than in terms of local effects on surface water. The arbitrary 5 L/s threshold is determined as the total rate of groundwater abstraction per land parcel (consistent with existing Regional Freshwater Plan Rule 7) to avoid a situation where Category B controls could be circumvented by utilising multiple bores pumping at a low rate.

3.2.3 Pumping regulation

As illustrated in Figure 3.3 the rate at which stream depletion effects dissipate after pumping ceases declines for groundwater takes with lower hydraulic connectivity. As a consequence, while pumping regulation offers an effective means to mitigate potential effects on surface water where there is a high degree of hydraulic connection, stream depletion effects tend to persist for a longer time after pumping ceases where there is lower connectivity. This situation creates a trade-off between the overall magnitude of stream depletion (as a percentage of the pumping rate) and the ability to control resulting effects in a temporal sense.

Table 3.1 shows the effect of varying hydraulic connectivity on the calculated reduction in stream depletion effect following the cessation of pumping[9]. These data show that for aquifers with a relatively high degree of hydraulic connection to surface water (e.g. q/Q = 0.8) the calculated direct stream depletion effect from groundwater abstraction reduces by over 50% 10 days after pumping stops. However, where there is a lower degree of hydraulic connection (e.g. q/Q = 0.4), stream depletion effects may continue to increase for a period after pumping stops[10] then decline slowly over time.

9 Calculated for a range of aquifer hydraulic properties using the Hunt (1999) methodology.

10 The continued increase in stream depletion once pumping stops illustrates the increasing lag which occurs where there is a low hydraulic connection between an individual bore and hydraulically connected surface water.

Table 3.1: Percentage reduction in stream depletion following cessation of pumping for a range of hydraulic connectivity (q/Q) values (assuming 100 days continuous abstraction prior)*

	Time since pumping stopped			
q/Q	10 Days	20 days	30 days	40 days
0.8	54%	71%	79%	83%
0.7	31%	53%	64%	71%
0.6	13%	34%	48%	57%
0.5	2%	18%	32%	43%
0.4	-4%	2%	13%	24%

* Calculated using the Hunt (1999) methodology.

From the range of values presented in Table 3.1 it is clear that there is no clearly identifiable point at which pumping regulation can be judged to be an effective option for mitigating stream depletion effects. However, when viewed in the context of typical low flow periods in the Wairarapa Valley (~4 to 6 weeks), it is clear that pumping regulation on groundwater takes where q/Q is less than 0.6 is likely to provide limited mitigation of the effects of groundwater abstraction on stream flow during critical periods. For example, the calculations shown indicate the stream depletion effect resulting from a groundwater take with a q/Q of 0.6 will reduce by approximately 50% within 30 days after pumping stops, while a take with a q/Q of 0.4 will show a reduction of only 13% over the same period. Therefore a nominal q/Q of 0.6 should be utilised as the threshold above which groundwater takes are subject to pumping regulation applies.

However, along with the degree of hydraulic connection, the overall rate of groundwater abstraction also influences the potential magnitude of streamflow depletion. For example, as shown in Figure 3.5, a groundwater take with a relatively high degree of hydraulic connection (e.g. q/Q of 0.7) may have a significantly lower overall effect on surface water than a take with a lower degree of hydraulic connectivity but a higher abstraction rate. Accordingly, groundwater takes from Category B should also subject to pumping regulation if they exceed a nominal rate of stream depletion of 10 L/s calculated on the basis of the average seasonal abstraction rate. Although pumping regulation may not necessarily provide a significant reduction in overall stream depletion effect from such takes in percentage terms, the actual volumetric reduction in effect for larger takes is likely to be sufficient to at least partially mitigate effects on surface water[11].

[11] Overseas experience suggests that hydraulic connection (or distance) criteria on their own may not be entirely effective in all situations for managing the overall magnitude of stream depletion effects where large takes can be located to avoid requirements for minimum flow controls (e.g. in the case of the proposed management options, a large take could be located so as to justify a q/Q <0.6 but still result in a significant effect on surface water). A stream depletion rate threshold is proposed to ensure such takes can effectively be managed.

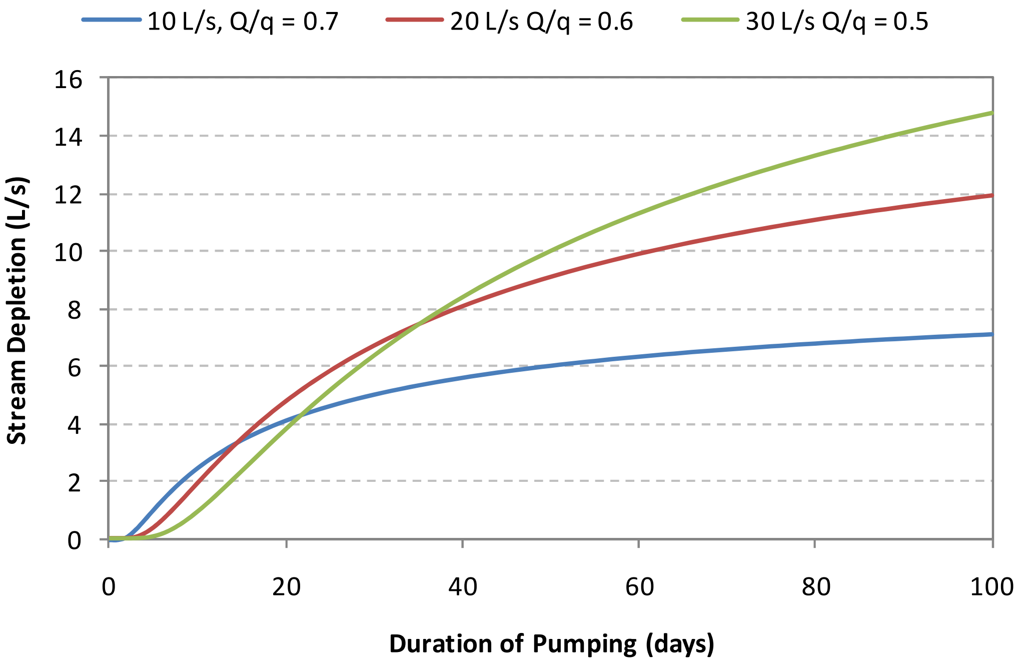

Figure 3.5: Calculated stream depletion resulting from groundwater takes with varying degrees of hydraulic connection (q/Q = 0.5–0.7) and pumping rates (Q = 10–30 L/s)

In summary, groundwater takes from Category B areas should be subject to pumping regulation based on minimum flows and water levels in relevant hydraulically connected surface water bodies where either q/Q >0.6 or the calculated stream depletion effect exceeds 10 L/s.

3.2.4 Allocation

In order to account for the potential effects of groundwater abstraction from Category B takes the following applies:

- Where the potential effect of groundwater abstraction meets the criteria for application of pumping regulation (i.e. q/Q >0.6 or calculated stream depletion effect >10 L/s) the calculated stream depletion effect is included in the primary allocation for relevant hydraulically connected surface waterbodies with the balance of the seasonal allocation included in the groundwater allocation for the relevant water management zone;

- Where the potential stream depletion effect does not meet the criteria for application of pumping regulation (i.e. q/Q <0.6 and calculated stream depletion effect <10 L/s) the take is counted as part of the total groundwater allocation for the relevant water management zone.

3.2.5 Assessment requirements for takes in Category B areas

Assessment of the nature and magnitude of potential stream depletion effects resulting from groundwater abstraction in Category B areas requires a hydrogeological assessment utilising relevant analytical or numerical modelling techniques. Such assessment will require development of a conceptual model of the hydrogeological setting of the proposed take informed by results of aquifer testing at the proposed abstraction point, and supplemented by geological and hydrogeological data (including water quality) from the surrounding area.

Basic calculation of the potential magnitude of stream depletion effects can be undertaken utilising analytical modelling techniques such as Jenkins (1977), Hunt (1999) and Hunt (2003). It is anticipated such techniques will be the most commonly utilised methods for estimating direct stream depletion effects for individual resource consent applications[12]. However, in some situations, such as very large takes, or where abstraction is particularly contentious, it may also be appropriate to utilise a numerical groundwater model (either the GWRC groundwater model or a suitable alternative).

One limitation of current analytical techniques is they are typically based on an assumption of aquifer heterogeneity (i.e. aquifer hydraulic properties do not vary spatially). In some areas of the Wairarapa Valley, there is a large contrast in aquifer permeability between the alluvial fan gravels and the reworked Q1 gravel aquifers (commonly up to one order of magnitude). While this non-uniform geological setting can be accounted for in numerical model simulations, it is more difficult to account for using analytical methods. In this situation one simple approach to address this issue (and provide a conservative estimate of potential stream depletion) may be to calculate the potential magnitude assuming the stream is located at the outer boundary of the adjacent Category A areas (since it is proposed to effectively manage these aquifers as part of the surface water system). Alternatively, it may be possible to develop a simple arithmetic relationship for applying analytical models in such situations using the results of numerical modelling (e.g. utilising a composite aquifer transmissivity or separation distance).

The calculation of potential stream depletion effects is based on seasonal pumping at the maximum rate sought by a consent applicant (i.e. pumping at the maximum daily rate for the maximum continuous period provided for by the seasonal allocation). Alternatively, where intermittent abstraction is proposed, effects should be calculated based on pumping at the average weekly pumping rate over the seasonal duration of the proposed abstraction.

Where a proposed groundwater take may affect more than one surface water body, assessment of the potential relative effect on each should be calculated either by application of relevant guidance for the application of analytical assessment techniques (e.g. Environment Canterbury 2000) or by use of a numerical model.

3.3 Spatial and depth distribution of hydraulic connectivity categories

The geographical distribution of Category A and Category B classifications is illustrated on Figure 3.6 (further versions of Figure 3.6 that focus on the Upper, Middle and Lower valleys are provided in Appendix G). This map is coloured

12 Physical measurement (e.g. flow gauging) to determine the potential magnitude of stream depletion is typically problematic as a means to quantify potential stream depletion effects due to a combination of factors including errors inherent in streamflow measurements, natural variability in catchment discharge, the location of suitable measurement points and the time lag between pumping and effects and the overall duration of measurement. As a consequence, direct measurement of effects on surface water is typically only suitable for large-scale takes situated immediately adjacent to hydraulically connected surface water bodies.

to illustrate the spatial distribution of the hydraulic connectivity zones at the land surface with the depth distribution of the various hydraulic connection categories identified for each water management zone.

For example, the riparian margin of Mangatarere Stream is designated Category A to 20 metres (depth), Category B between 20 and 30 metres and Category C at depths greater than 30 metres. The width of each of the hydraulic conductivity categories in this area is determined on the basis of geology and results of numerical model simulations (further described in Appendix E). To illustrate the three-dimensional nature of the hydraulic connectivity zonation, Figure 3.7 and Figure 3.8 show the depth distribution of the various hydraulic connection categories along the two section lines marked on Figure 3.6.

Numerical model analysis undertaken to determine the spatial and depth distribution of the hydraulic connectivity zonation is described in detail in Appendices D to F for each individual water management zone.

Interpreting the map

Management zones

Zone name and boundary

Abstraction categories – spatial extent

Category A

Category B

Category C

Abstraction categories – depth extent

A
—20
B
—30
C

This example is for a bore located within a Category A spatial zone (e.g. like that in the Mangatarere management zone in the map).

Bores drawing water from a depth of less than 20 m remain Category A, but if they are between 20 and 30 m they become Category B and Category C if they are deeper than 30 m

See Figures 3.7 and 3.8 for further illustration of depth categories

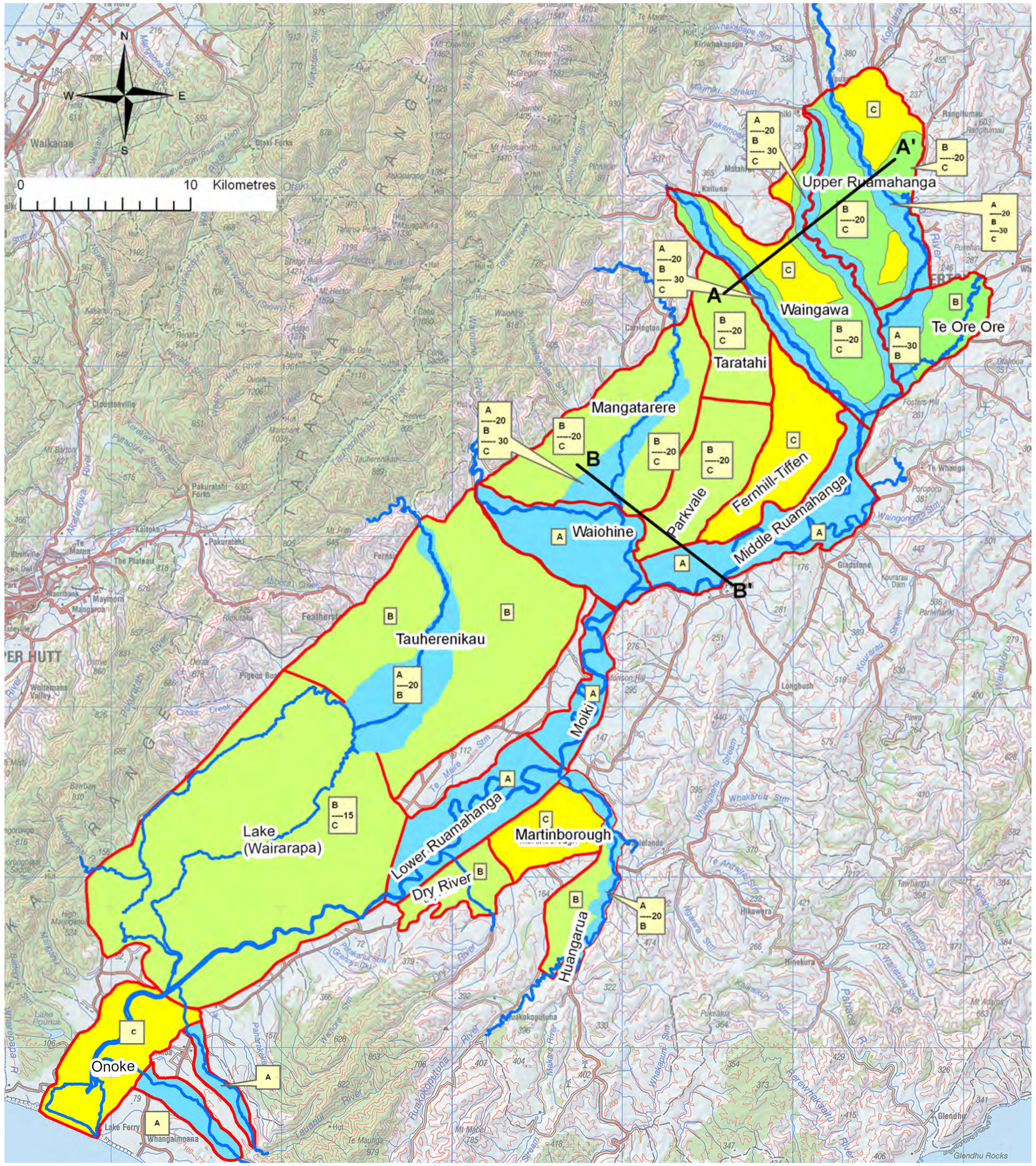

Figure 3.6: Geographical (spatial) and depth distribution of hydraulic connectivity categories across the Wairarapa Valley. Cross sections A–A` and B–B` are illustrated in Figures 3.7 and 3.8.

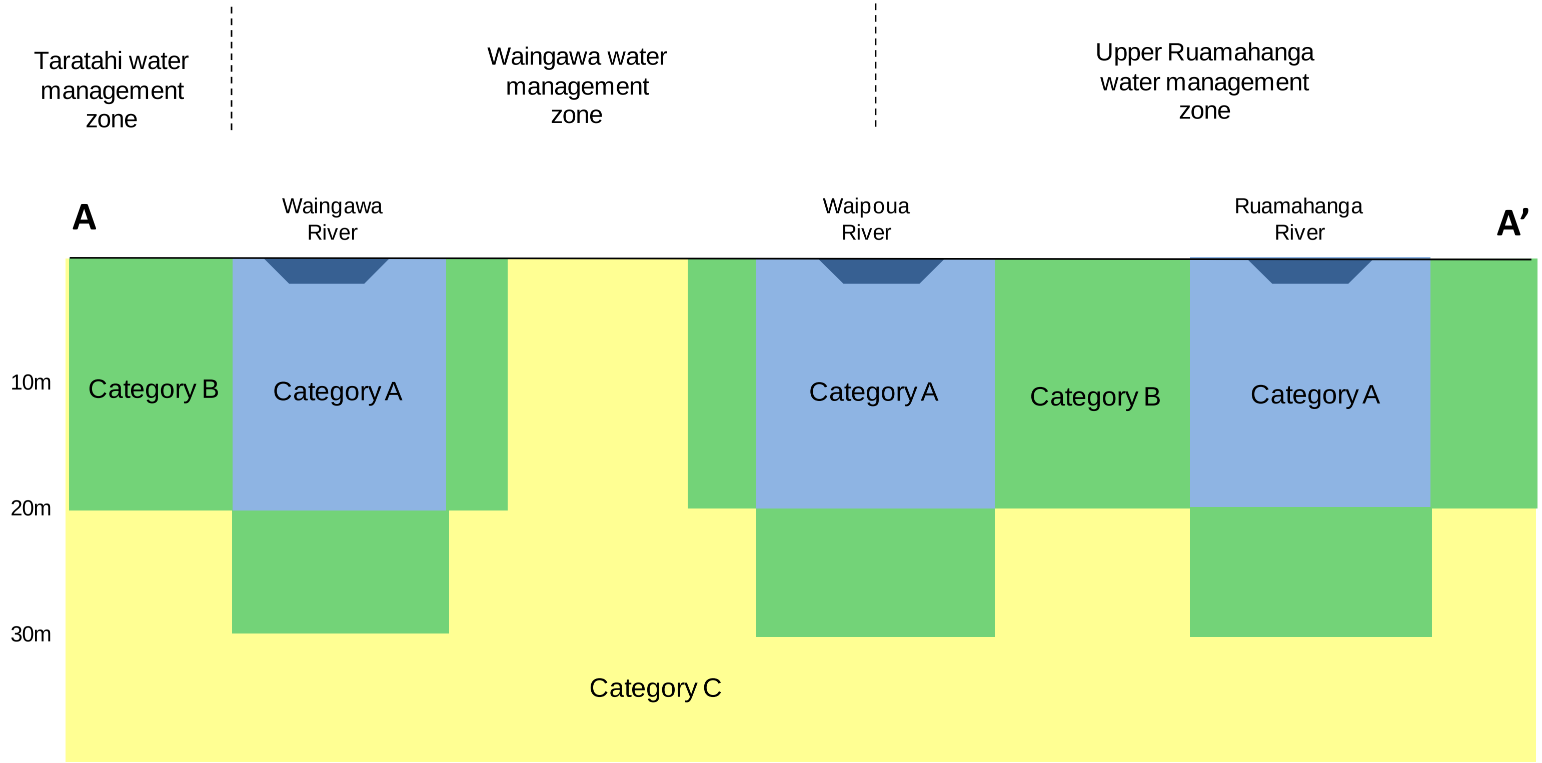

Figure 3.7: Schematic cross section illustrating depth distribution of hydraulic connectivity categories along section A-A' in Figure 3.6 (not to scale)

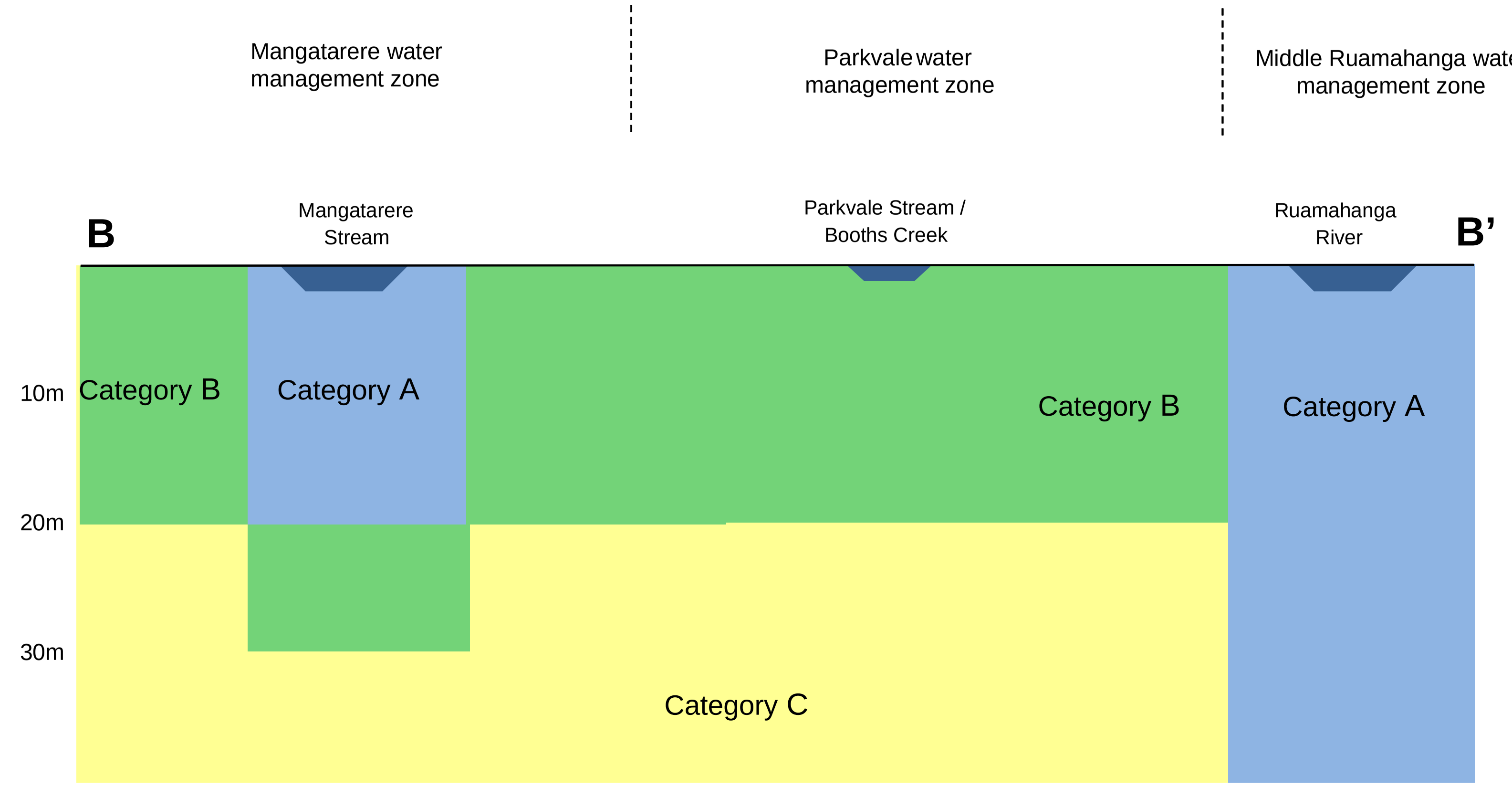

Figure 3.8: Schematic cross section illustrating depth distribution of hydraulic connectivity categories along section B-B' in Figure 3.6 (not to scale)

3.4 Summary of approach for managing direct stream depletion effects

3.4.1 Category A

In order to manage direct stream depletion, hydraulic connectivity classification (Category A) within which groundwater abstraction is effectively managed as part of the environmental flow and water level regime established for relevant hydraulically connected surface water bodies. Category A effectively encompasses the portion of the hydrogeological system which exhibits a direct and immediate hydraulic connection with surface water.

Spatial Definition	Generally limited to the Q1 gravel aquifers along the riparian margins of the major rivers (the Ruamahanga, Waipoua, Waingawa, Waiohine, Tauherenikau and Huangarua rivers and Mangatarere Stream). The extent of proposed Category A is shown in Figure 3.6 and described in detail in Appendices C to F.
Application	All groundwater takes which require resource consent (i.e. excludes permitted uses under Section 14(b) of the Resource Management Act 1991and takes permitted under the existing RFP (WRC 1999).
Pumping Regulation	Groundwater takes requiring resource consent are subject to minimum flow or water level controls set for hydraulically connected surface water bodies.
Allocation	Groundwater abstraction from Category A aquifers are included in the primary allocation for hydraulically connected surface water based on the average weekly rate of groundwater abstraction
Assessment Requirements	No specific assessment of stream depletion required. However, assessment to determine localised effects of groundwater abstraction (e.g. interference drawdown) or impacts on the surface water environment (e.g. effects on aquatic ecology) may still be required to support individual resource consent applications.

3.4.2 Category B

Category B includes those components of the hydrogeological system which exhibit a moderate to high degree of connectivity with surface water but where application of pumping regulation may or may not provide effective mitigation of stream depletion effects depending on local hydrogeological conditions and the rate of groundwater abstraction. The management regime for Category B can be summarised as:

Spatial Definition	The spatial extent of Category B has been determined for each water management zone based on observed hydrogeological characteristics and modelling of potential stream depletion effects resulting from groundwater abstraction. Category B forms a buffer zone along the outer margin of the Q1 aquifers and also includes areas of the Q2 alluvial fans aquifers which exhibit potential hydraulic connection to local surface water (either Category A aquifers or local spring-fed streams and wetlands). The extent of the Category B areas in each individual water management zone is shown in Figure 3.6 and described in Appendices D to F.
Application	All takes with a weekly average abstraction rate >5 L/s require assessment of potential stream depletion effects.
Pumping Regulation	Groundwater takes from Category B areas are subject to minimum flow or water level controls (based on those established for hydraulically connected surface water bodies) when the calculated stream depletion effect exceeds 60% (i.e. q/Q>0.6) of the seasonal average pumping rate or is greater than 10 L/s calculated using the average seasonal abstraction rate.
Allocation	Calculated stream depletion effect from those takes subject to minimum flow control are included in primary allocation for relevant hydraulically connected surface waterbodies with the balance of seasonal allocation counted as part of the total groundwater allocation for the relevant water management zone. Remaining takes (including those with a weekly average rate of take <5 L/s) are counted as part of the total groundwater allocation for the relevant water management zone.
Assessment Requirements	Hydrogeological assessment of potential stream depletion utilising relevant numerical or analytical modelling techniques based on the cumulative (direct) stream depletion effect on hydraulically connected surface water. Assessment of stream depletion effects should be based on continuous abstraction at the long-term average abstraction rate being sought.

3.4.3 Category C

The final component of the conjunctive water management framework for the Wairarapa Valley is designated as Category C. This classification includes those components of the hydrogeological system which exhibit a moderate to low degree of connectivity with surface water where application of pumping regulation is unlikely to provide mitigation of stream depletion effects during low flow periods. In these areas spatially defined management units (water management zones) are assigned volumetric allocation limits that take account of the potential effects of groundwater abstraction on river or stream baseflow at a catchment scale. The conjunctive water management framework, including options for volumetric allocation limits, are outlined in Section 4 and described in detail in Appendices D to F.

4. Management of the cumulative effects of groundwater abstraction on river baseflow

As outlined in Section 2, there are two main components of the framework for conjunctive management of groundwater and surface water resources in the Wairarapa Valley:

1. Active management of direct stream depletion effects resulting from groundwater abstraction in aquifers (Category A and part Category B) that exhibit a direct or immediate hydraulic connection with surface water where such effects can be mitigated by application of temporal pumping restrictions. For such groundwater takes, temporal pumping restrictions are established according to environmental flows and water level policies for hydraulically connected surface waterbodies to mitigate effects during low flow periods (refer to Section 3 for details).

2. Sustainable groundwater allocation limits at a catchment or sub-catchment scale to manage the cumulative effects of groundwater abstraction (Category C and part Category B), on river and stream baseflow[13].

This section provides an overview of the methodology developed to manage the cumulative effects of groundwater abstractions on sub-catchment baseflow through the definition of water management zones and associated allocation limits. Details of the extensive analysis undertaken to delineate groundwater allocation limits for individual water management zones are provided in Appendices D to F.

4.1 Water management zones

The management of the cumulative effects of groundwater abstractions with a moderate to low connection to surface water has been approached by delineating '*water management zones*' within each of the three Wairarapa Valley catchments (Upper, Middle and Lower). These zones are essentially discrete management units based on groundwater and surface water sub-catchment mapping. Zone delineation criteria include surface water catchment boundaries, hydraulic or physical groundwater flow system boundaries, the conceptual hydrogeological functioning of the zone and its context within the larger groundwater catchment.

The zones are designed so that the management of surface water resources can be easily integrated with groundwater allocation, thereby allowing the cumulative effects of groundwater abstraction on sub-catchment baseflow to be accounted for at a catchment or sub-catchment scale (i.e. enabling conjunctive management of groundwater and surface water resources).

It is important to recognise the water management zones are not, in most instances, isolated management units. Most zones have 'soft' boundaries based on hydraulic divides or represent transitional areas within a continuous groundwater flow system. Where significant interactions between zones are recognised, the sensitivity of cross-zone groundwater fluxes to the cumulative

13 In this context baseflow refers to groundwater discharge to surface water bodies including spring-fed streams.

effects of abstraction has been evaluated and provision is made in the proposed allocation options.

4.2 Groundwater allocation limits

Sustainable groundwater allocation limits are recommended for each zone based on the outputs of abstraction scenarios run on the numerical groundwater flow models developed for each catchment (Gyopari and McAlister 2010a, b and c). These models simulate the cumulative effects of groundwater abstraction in terms of surface water depletion, aquifer drawdown, and changes in cross-zone throughflow dynamics. This information provides the basis for developing sustainable groundwater allocation limits for each water management zone. Where appropriate, the recommended groundwater allocation limits (presented later in Section 4.6**)** are referenced to a potential cumulative effect on baseflow in relevant hydraulically connected surface water bodies**.**

For most water management zones the cumulative effect of groundwater abstractions is managed in relation to the long-term effect on river baseflow within the zone (or sub-catchment). In the context of this report, a manageable (or a perceived acceptable) effect on baseflow is considered in terms of a 'baseflow allocation' which represents the rate at which natural catchment discharge (occurring during stable, low flow conditions) is likely to be depleted by the effects of groundwater abstraction which cannot be mitigated by temporal controls on groundwater abstraction (i.e. pumping regulation). Cumulative depletion effects can be expressed as a proportion of baseflow in the principal surface water systems within a particular sub-catchment. In this report, the naturalised[14] 7-day Mean Annual Low Flow (MALF) has been used as the river and stream baseflow index against which depletion effects are assessed. The use of MALF is consistent with the approach taken by GWRC to managing the impacts of direct abstractions from river and streams (described in Thompson, 2014). MALF has been used as a reference point for setting minimum flows and maximum allocation rates. MALF has been demonstrated in New Zealand to have an explicit ecological basis i.e it is a low flow with a sufficiently frequent return period (between 1-2 years) that is likely to be a significant limiting factor, with respect to fish assemblages in particular. MALF therefore has common acceptance as a suitable reference point for abstraction management. Nevertheless, there are many other instream values for which flow dependencies are not well understood and using MALF can only be viewed as a broad surrogate for these values.

Baseflow allocation may be taken into consideration in the formulation of future surface water allocation policy, or may simply be an acknowledged, but separately managed, quantity. Different approaches to establishing baseflow allocation may also be adopted in different water management zones reflecting the hydraulic characteristics and values associated with different surface water environments. As a result, the initial step in determining appropriate groundwater allocation thresholds for the various water management zones is determination of an acceptable level of effect at a sub-catchment scale. Once

[14] Where the measured or estimated mean annual low flow has been adjusted to compensate for surface water abstractions and some riparian groundwater abstractions (ie these abstractions are 'added' back in to the flow record).

an acceptable level of effect has been determined, a corresponding groundwater allocation volume can be back-calculated using the relevant baseflow allocation for each individual water management zone (as determined by numerical modelling). In this regard, a range of potential groundwater allocation options have been developed for each water management zone to enable an acceptable level of effect to be selected. While the options presented are typically centred on current levels of allocation, data are also presented to allow for alternative allocation options to be easily calculated.

The methodology is therefore 'effects-based' and produces an outcome focussed on environmental sustainability. This approach is very different from the traditional groundwater allocation methodology of assigning a proportion of the system input, typically specified in terms of land surface recharge (LSR). It must be noted however that judgements about acceptable level of effect have not been based on an explicit consideration of *all* relevant instream values for each zone. Rather, they are based on broad expectations about what level of additional abstractive impact might be considered acceptable given current understandings about general catchment condition and instream values. It is anticipated that recommended groundwater allocation limits in this report may need to be further refined during catchment committee processes (termed 'whaitua'[15]) that are planned for coming years.

It is noted that the conjunctive water management framework for the Wairarapa Valley described in this report relies heavily on the application of numerical groundwater modelling. As described in Gyopari and McAlister (2010a, b and c), the transient flow models utilised for the assessment were developed from the verified conceptual hydrogeological models and qualitatively and quantitatively calibrated to field measurements of groundwater level and fluxes to and from surface water environments following procedures that minimise non-uniqueness and predictive uncertainty. Therefore, while the current model set up and calibration represent the current 'state of knowledge', it is acknowledged there are inherent limitations in the accuracy and resolution of these tools for evaluation of abstraction scenarios, particularly at the localised scale.

Appendix D provides a detailed description of the water management zones defined for the Upper Valley catchment and outlines the analysis undertaken to develop the groundwater allocation options for each zone. Appendix E and Appendix F outline similar analyses for the Middle and Lower Valley catchments respectively.

[15] 'Whaitua' is a term used to describe a catchment committee process being established in the Wellington region (from late 2013). Five whaitua are proposed, covering each of the Ruamahanga River catchment, the eastern Wairarapa hill country, the Hutt River and wellington Harbour catchment, Porirua Harbour catchment and the Kapiti Coast. The whaitua will develop a set of recommendations that may supercede many of the regional plan provisions, including interim minimum flow and allocation limits.

4.3 Water management zones in the Upper Valley catchment

Figure 4.1 shows the spatial extent of the three water management zones in the Upper Valley catchment. The management objectives and allocation criteria for each zone are summarised in Table 4.1. The zones are based primarily on surface water and groundwater catchments, but are also locally constrained by geological boundaries. The delineation of water management zones is therefore based on the conceptual hydrogeological model and the recognition of distinct hydrogeological domains. The rationale behind each zone boundary and analysis undertaken to derive the groundwater allocation options and recommended allocation limits for each are provided in Appendix D.

Figure 3.6 shows the existing RFP (WRC 1999) groundwater management zones and outlines the new water management zones to enable cross-referencing.

Table 4.1: Water management zones, management objectives and allocation criteria for the Upper Valley catchment

Zone name	Area (km^2)	Management objectives	Allocation criteria
Te Ore Ore	27.1	• Managing baseflow depletion in the Ruamahanga River and Poterau Stream	• Ruamahanga River (MALF) • Poterau Stream (MALF) • Rainfall recharge
Waingawa	77.7	• Managing baseflow depletion in the Waingawa and Waipoua Rivers and Masterton Springs	• Combined discharge (MALF) for: – Waingawa River – Waipoua River – Masterton Springs • Recharge
Upper Ruamahanga	72.0	• Managing baseflow depletion in the Ruamahanga and Waipoua Rivers	• Recharge • Ruamahanga and Waipoua rivers (MALF)

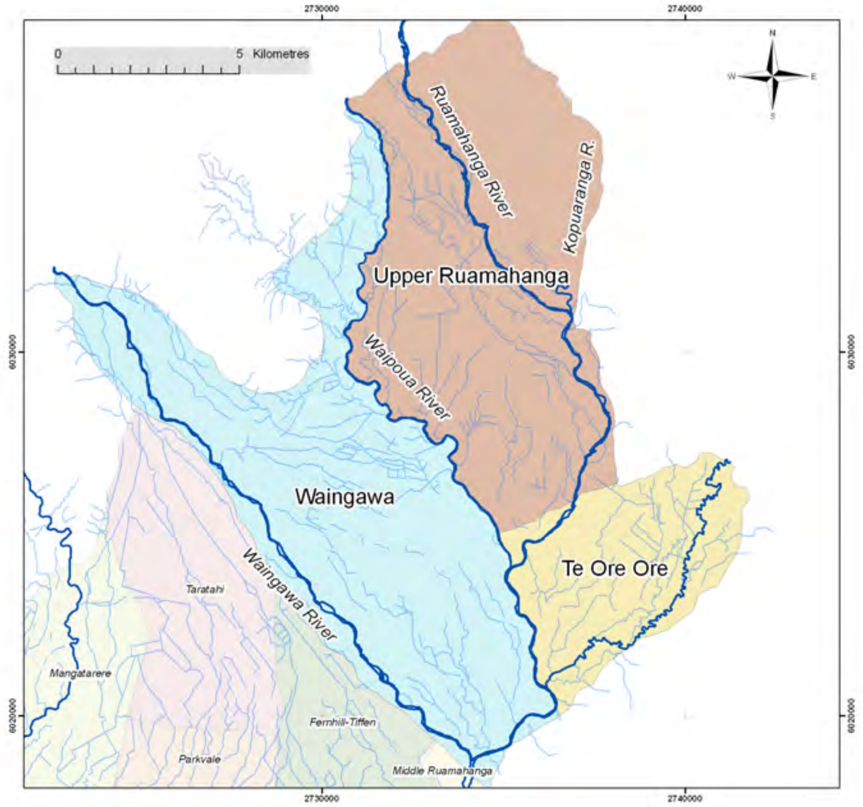

Figure 4.1: Water management zones in the Upper Valley catchment

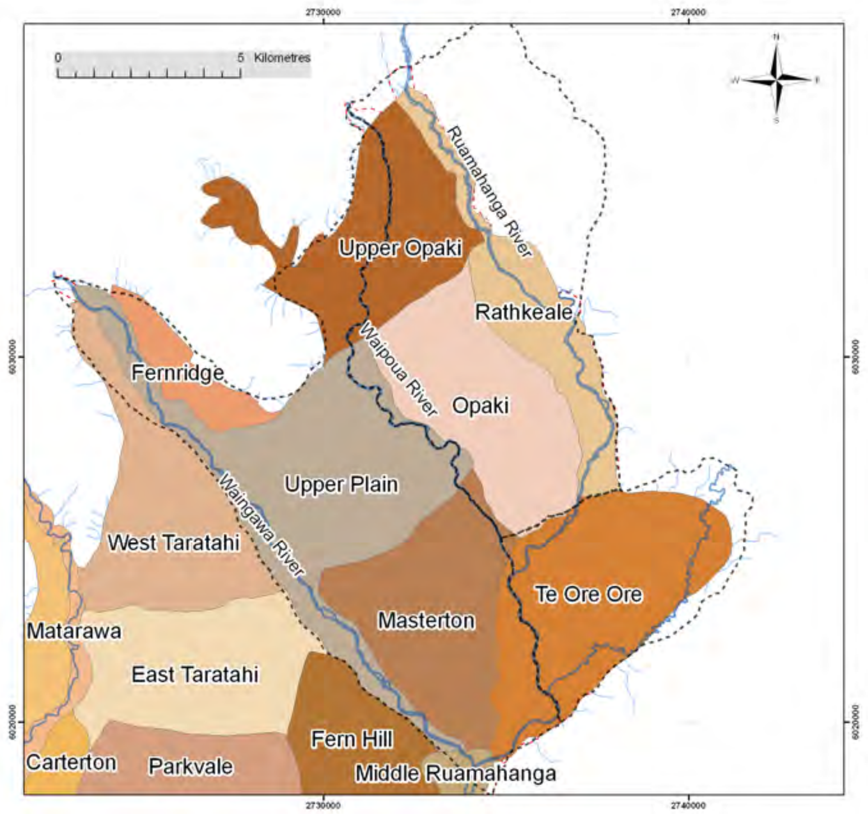

Figure 4.2: Map showing the extent of existing RFP (WRC 1999) groundwater zones in the Upper Valley catchment (spatial extent of water management zones indicated by black dashed lines)

4.4 Water management zones in the Middle Valley catchment

Figure 4.3 shows the spatial extent of the six water management zones for the Middle Valley catchment. The management objectives and allocation criteria for each zone are summarised in 4.2. The zones are based primarily on surface water and groundwater catchments but are also locally constrained by geological boundaries. The delineation of water management zones is therefore based on the conceptual hydrogeological model and the recognition of distinct hydrogeological domains. The rationale behind each zone boundary as well as analysis undertaken to derive the groundwater allocation options and recommended allocation limits for each are provided in Appendix E.

Figure 4.4 shows the existing RFP (WRC 1999) groundwater management zones and outlines the new water management zones to enable cross-referencing.

Table 4.2: Water management zones, management objectives and allocation criteria for the Middle Valley catchment

Zone name	Area (km^2)	Management objectives	Allocation criteria
Waiohine	39.2	• Managing baseflow depletion in the Waiohine River, Papawai-Tilsons-Muhunoa springs	• Waiohine River (MALF) • Greytown springs (MALF)
Mangatarere	78.3	• Managing baseflow depletion in the Mangatarere Stream including spring-fed tributaries	• Mangatarere Stream MALF at Waiohine confluence
Parkvale	37.4	• Managing baseflow depletion in the Parkvale Stream, Booths Creek • Confined aquifer drawdown	• Parkvale springs mean flow • Drawdown threshold
Taratahi	29.3	• Managing baseflow depletion in the springs and wetlands associated with major faults	• Masterton and Carterton faultline springs (MALF)
Fernhill-Tiffen	38.1	• Drawdown	• Rainfall recharge
Middle Ruamahanga	43.8	• Managing baseflow depletion in the Ruamahanga River	• Ruamahanga River (MALF)

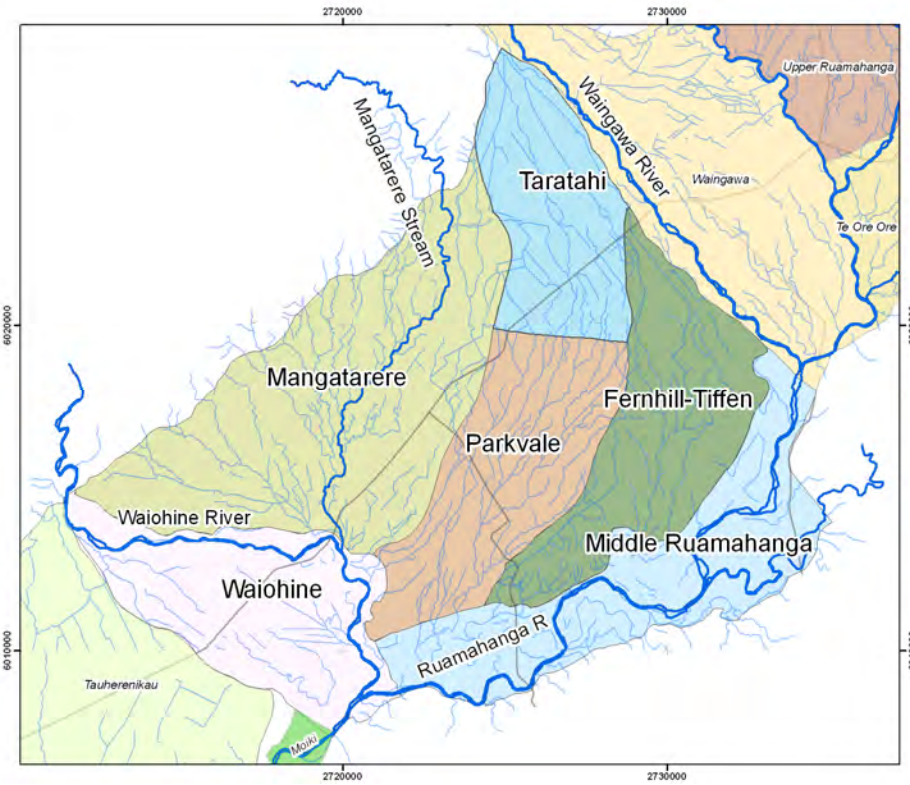

Figure 4.3: Water management zones in the Middle Valley catchment

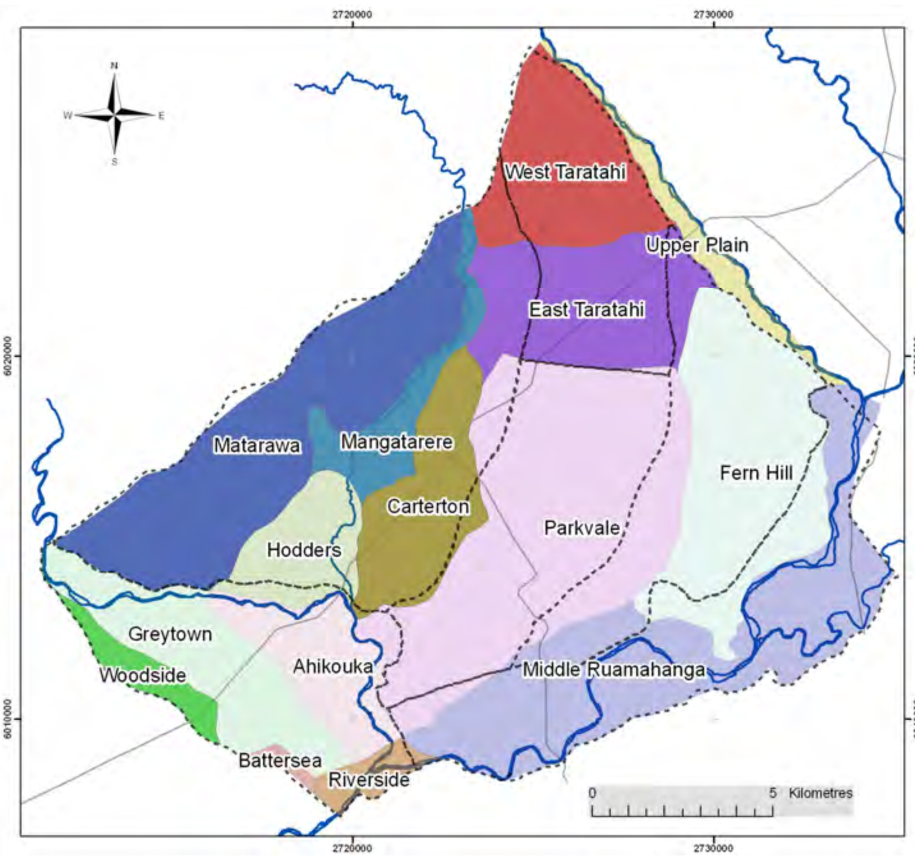

Figure 4.4: Map showing the spatial extent of existing RFP (WRC 1999) groundwater management zones in the Middle Valley (spatial extent of water management zones indicated by black dashed lines)

4.5 Water management zones in the Lower Valley catchment

Figure 4.5 shows the spatial extent of the eight water management zones in the Lower Valley catchment. The management objectives and allocation criteria for each zone are summarised in Table 4.3. Unlike the Upper and Middle Valley catchments, the hydrogeological setting in the Lower Valley catchment is considerably more complex and ranges from shallow, unconfined areas in close contact with the surface water environment to deep confined aquifers (such as the Lake basin) which are remotely recharged from unconfined aquifers.

The delineation of water management zones in the Lower Valley catchment is therefore based on the conceptual hydrogeological model and the recognition of distinct hydrogeological environments. The zone design takes into consideration surface water catchments in combination with groundwater recharge and discharge areas. The rationale behind the identification of each zone is provided in the relevant report sections and further detailed information is provided by Gyopari and McAlister (2010c).

Many of the Lower Valley water management zones are interconnected and represent parts of a continuous flow system from recharge areas on the Tauherenikau fan and Ruamahanga valley, to spring discharge areas on the lower fan areas and vertical leakage out of the Lake basin area. Water management zones which exhibit significant interdependence (or cross-zone interference effects), especially when they are pumped, are the Tauherenikau, Moiki, Lower Ruamahanga and Lake zones. The interactions between these zones and abstraction-induced interference effects between them have been taken into consideration when determining sustainable allocation limits.

Figure 4.6 shows the current RFP (1999) groundwater management zones in the Lower Valley catchment. The outlines of the new water management zones are superimposed on this map for cross-reference purposes.

Table 4.3: Water management zones, management objectives and allocation criteria for the Lower Valley catchment

Zone name	Area (km²)	Management objectives	Allocation criteria
Tauherenikau	152	• Managing baseflow depletion in the Tauherenikau River and associated spring-fed stream systems • Effects on throughflow into Lake Zone	• Tauherenikau River (MALF) • Stonestead Creek (MALF) • Featherston Springs (MALF) • Otukura Stream (MALF)
Moki	18	• Managing baseflow depletion in the Ruamahanga River	• Ruamahanga River (MALF)
Lower Ruamahanga	39	• Managing baseflow depletion in the Ruamahanga River • Throughflow into Lake Zone	• Ruamahanga River (MALF)
Martinborough	22.4	• Throughflow into Lower Ruamahanga zone • Drawdown	• Rainfall recharge
Dry River	16.7	• Throughflow into Lower Ruamahanga zone • Drawdown	• Rainfall recharge
Huangarua	22.5	• Managing baseflow depletion in the Huangarua River	• Rainfall recharge
Lake	219.3	• Throughflow effects on adjacent water management zones • Drawdown • Discharge to Lake Wairarapa	• Discharge to Lake Wairarapa
Onoke	40.4	• Discharge to coastal margin • Throughflow to Lake Zone • Managing baseflow depletion in the Turanganui and Tauanui Rivers	• Turanganui River • Tauanui River • Throughflow recharge from side valleys • Discharge to Ruamahanga River and Lake Onoke

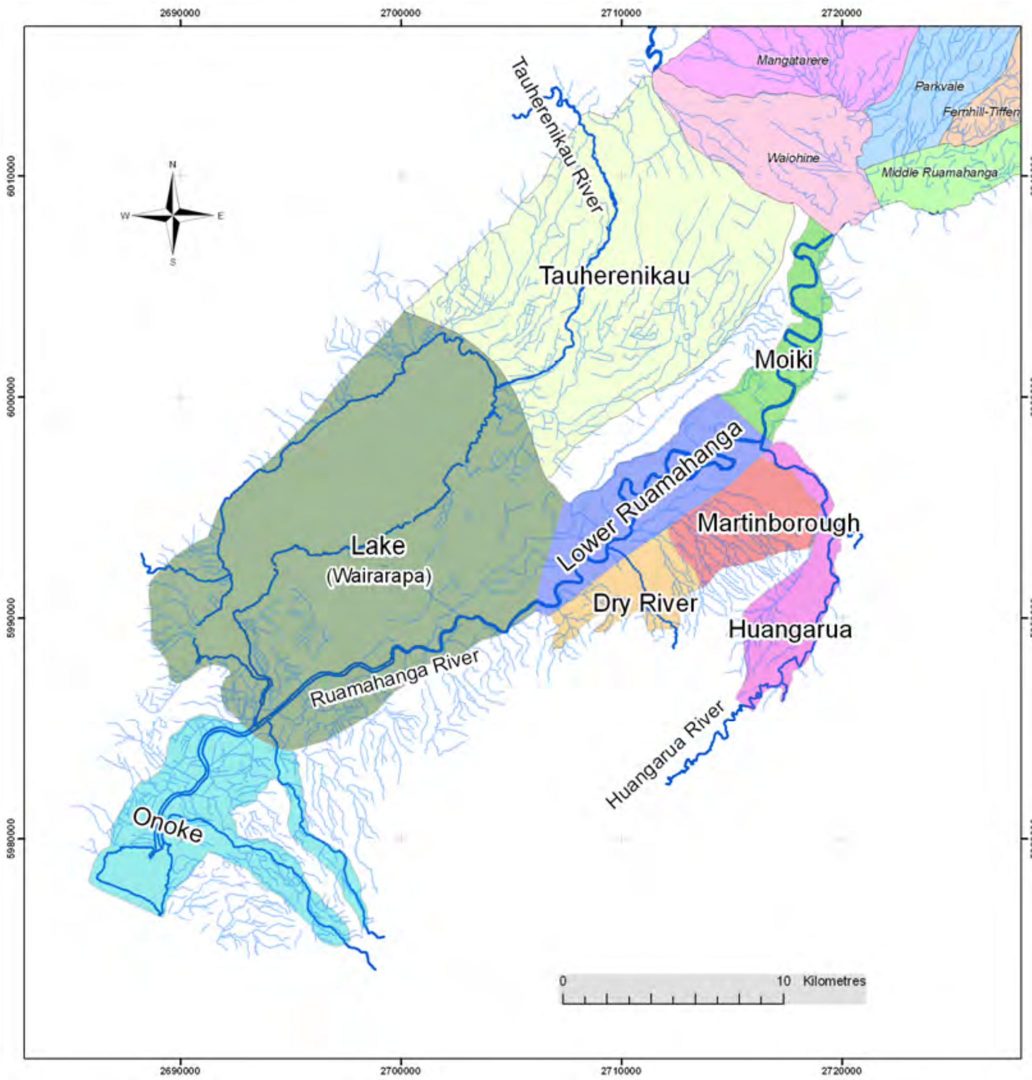

Figure 4.5: Spatial extent of water management zones in the Lower Valley catchment

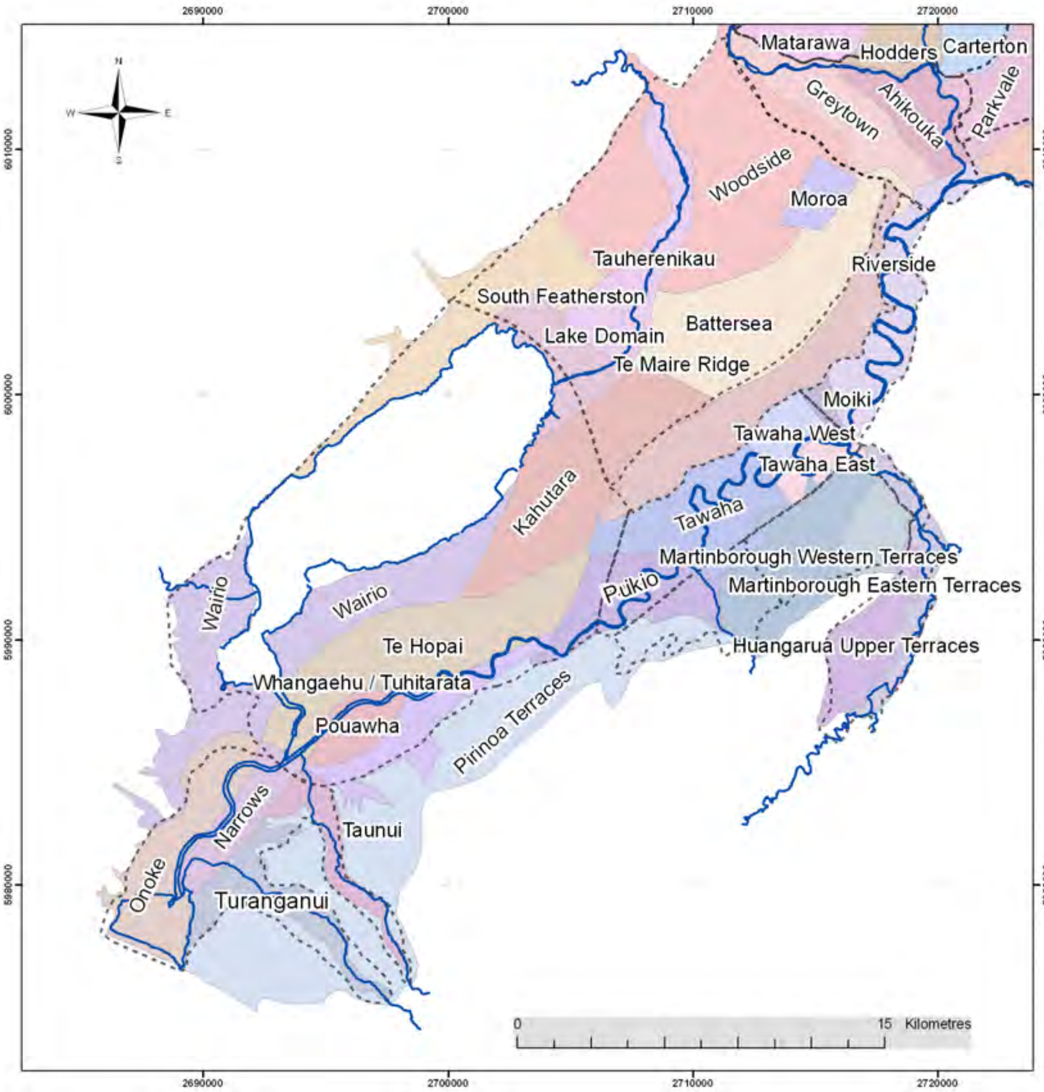

Figure 4.6: Map showing the spatial extent of existing RFP groundwater management zones in the Lower Valley, with the spatial extent of the new water management zones indicated by black dashed lines

4.6 Summary of groundwater allocation options and recommended limits

Tables 4.4 to 4.6 provide a summary of the groundwater allocation options and recommended limits for the water management zones in each of the Upper, Middle and Lower Valley catchments respectively. Appendices D to F provide a detailed outline of the methodology used to derive the allocation options and recommended limits for each zone. The tables provide the following information:

Aquifers:	Aquifer systems identified in the zone, either regarded to be a single groundwater resource, or separate resources.
Management objectives:	The principal objectives to be met by a sustainable groundwater allocation policy. Most commonly, these are managing cumulative baseflow depletion in

principal surface water environments within the zones, or in adjacent hydraulically connected zones.

Allocation reference criteria:	Environmental flows usually relate to the mean annual low flow (MALF[16]) of critical surface water environments, and so simulated streamflow depletion effects have been referenced to this figure. Allocation options are therefore presented for a range of effects on MALF. A baseflow depletion factor (expressed as the calculated effect on surface water resulting from abstraction from the nominated groundwater zone as a percentage of the seasonal average abstraction rate (i.e. q/Q)) is also recommended (based on modelling). Mean annual land surface recharge (LSR) is used to determine sustainable allocation limits in water management zones where there are no hydraulically connected surface waterbodies or where there is insufficient characterisation of river or stream flows. A 'primary' designation means that the baseflow depletion factor was used to derive the allocation options. Frequently, these options are also referenced to other criteria such as LSR or throughflow as a second-level check on the appropriateness of the allocation options.
Groundwater - surface water management zones:	These refer to the A, B and C hydraulic connection categories described in Section 2. Groundwater allocation applies to Category C and the portion of groundwater allocation from Category B not meeting criteria for application of temporal pumping restrictions. The location and depth of each zone is specified.
Groundwater allocation options and recommended limits:	Allocation is calculated on the basis of an effect on the reference criteria (i.e. a x% depletion of MALF) using a baseflow depletion factor derived from numerical modelling (when allocation for the zone is based on surface water depletion). In this case, the reference flow is divided by the depletion factor to provide a groundwater abstraction rate which would cause the nominated rate of baseflow depletion. A range of allocation options are presented for each water management zone on the basis of a range of potential effects on the reference baseflow. From these ranges, an allocation limit has been recommended, the reasons for which are discussed for each zone in Appendices D to F. In some instances, allocation is based primarily on a proportion of the mean annual land surface recharge, as described in Appendices D to F. In the Lower Valley catchment groundwater abstraction from some of the proposed water management zones may potentially impact on the surface water systems in

[16] All MALF figures presented in this report are naturalised 7-day MALFs and have been estimated for the most downstream points in the respective catchments. However, the robustness of the estimates varies between catchments depending on data availability and quality. More detail on the MALF estimates is provided in Keenan (2009).

adjacent zones. In such instances, the depletion effect from an adjacent zone is also taken into account when establishing groundwater allocation volumes.

Allocation volumes: Expressed in m^3/day, m^3/week and m^3/year. The annual volume is based on a pumping duration of 180 days. It is probable that groundwater users would be restricted under weekly and annual pumping volumes to allow higher instantaneous abstractions.

The range of options provided in Tables 4.4 to 4.6 differs between management zones. For example, options for baseflow depletion of between 2% and 5% of MALF are given for the Waingawa Management Zone whereas the range is 10% to 25% of MALF for the Mangatarere Management Zone. This primarily reflects the difference between catchments in the current levels of allocation (and associated depletion effect) already occurring; that is, the current daily depletion effect in the Mangatarere is about 25% of MALF whereas it is less than 5% in the Waingawa. The options provided are therefore generally centred about the current situation as a starting point for looking at alternative scenarios of allocation and associated depletion effect.

With respect to the use of land surface recharge, the approach taken has been to cross reference allocation limits to the lower quartile of annual recharge (rather than the mean) and, as a general rule, keep allocation below 20−30% of lower quartile recharge. The basis for this approach is to allow contingency for successive dry years (when recharge is substantially less than normal); during such times, if allocation is referenced to a high proportion of the annual recharge, aquifers may be ‘mined’ or depleted to the extent that unacceptable impacts on surface water bodies and groundwater users occur.

There is no universally applied, quantitative, one-size-fits-all approach for determining acceptable levels of environmental risk. Therefore, arriving at a recommended limit for each zone was the result of considering all of the factors described above (ie, existing allocation and catchment stress, baseflow depletion and land surface recharge) and applying best judgement. However, it is also acknowledged that this risk assessment must ultimately take in a wider community view and include more explicit consideration of other values; for example, security of supply for water users and cultural wellbeing. Future application of the conjunctive water management framework may result in different levels of baseflow depletion being adopted for different sub-catchments and a consequent change in the amount of water deemed available to groundwater users.

Table 4.4: Summary of groundwater allocation framework including management options and recommended allocation limits (bolded) for Abstraction Categories B and C in water management zones in the Upper Valley catchment. [LSR = mean annual land surface recharge, LSR(LQ) = lower quartile of the annual land surface recharge, MALF = mean annual low flow].

Water management zone	Aquifers	Management objectives	Allocation reference criteria	Groundwater-surface water management zones	Groundwater allocation options	Daily allocation (m^3)	Weekly allocation (m^3)	Annual allocation ($m^3 \times 10^6$)
Te Ore Ore	1: Unconfined+ semi-confined	Baseflow depletion: • Ruamahanga River • Poterau Stream	Primary: Ruamahanga River 7-day MALF Reference to: • LSR and LSR(LQ) • Poterau Stream low flow	Western zone: Category A to 30 m; Category B >30 m Elsewhere all depths = Category B	MALF depletion			
					0.5%	2,660	18,600	0.48
					1.0%	5,200	31,200	0.94
					1.5%	8,000	56,000	1.44
Waingawa	1: Unconfined+ semi-confined	Baseflow depletion: • Waingawa River • Waipoua River • Ruamahanga River • Masterton springs	Primary: Combined MALF for Waingawa R, Waipoua R and Masterton springs. Reference to: • LSR and LSR(LQ)	Q1 alluvium or 500 m river buffer: Category A to 20 m; Category B to 30 m; Category C >30 m Masterton springs area + 500 m Category A buffer: Category B to 20 m; Category C >20 m Elsewhere = Category C	MALF depletion			
					2%	7,000	49,000	1.3
					3%	10,400	72,800	1.9
					4%	14,000	98,000	2.5
					5%	17,300	121,100	3.12
Upper Ruamahanga	1: Unconfined+ semi-confined	Baseflow depletion: • Waipoua River • Ruamahanga River	Primary: LSR and LSR(LQ)	Q1 alluvium or 500 m river buffer: Category A to 20 m; Category B to 30 m depth Between Waipoua and Ruamahanga. Rivers + Lower Kopuaranga River: Category B to 20 m depth; Category C >20 m Lansdowne Hill and elsewhere, >20 m: Category C	LSR(LQ)			
					15%	14,800	103,600	2.66
					20%	19,700	137,900	3.55

Table 4.5: Summary of proposed groundwater allocation framework including management options and recommended allocation limits (bolded) for Abstraction Categories B and C in water management zones in the Middle Valley catchment. [LSR = mean annual land surface recharge, LSR(LQ) = lower quartile of the annual land surface recharge, MALF = mean annual low flow]

Water management zone	Aquifers	Management objectives	Allocation reference criteria	Groundwater-surface water management zones	Groundwater allocation options	Daily allocation (m^3)	Weekly allocation (m^3)	Annual allocation ($m^3 \times 10^6$)
Waiohine	1: Unconfined (+semi-confined)	Baseflow depletion: • Waiohine River • Greytown springs	Waiohine River surface water allocation	All: Category A	Category A	n/a	n/a	n/a
Mangatarere	1: Unconfined + semi-confined	Baseflow depletion: • Mangatarere Stream • Springs	Mangatarere Stream 7-day MALF at Waiohine confluence Depletion factor = 0.5	Q1 alluvium + Beef Creek area: Category A to 20 m; Category B to 30m; Category C >30 m Elsewhere: Category B to 20 m; Category C >20 m	MALF depletion			
					10%	6,400	44,800	1.15
					15%	9,600	67,200	1.72
					20%	**12,800**	**89,600**	**2.3**
					25%	16,000	112,000	2.9
Parkvale	1: Confined 2: Unconfined	Baseflow depletion: • Parkvale Stream • Booths Creek Drawdown management: • Confined aquifers (<5 m drawdown)	Parkvale springs mean flow Depletion factors: Confined = 0.22 Unconfined = 0.3	All: Category B to 20 m; Category C >20 m	Spring low flow depletion Confined aquifer:			
					10%	**8,636**	**60,452**	**1.55**
					15%	12,960	90,720	2.33
					20%	17,280	120,960	3.11
					25%	21,672	151,704	3.90
					Unconfined aquifer:			
					3%	**1,900**	**13,300**	**0.342**
					5%	3,166	22,162	0.57
					10%	6,336	44,352	1.14
					15%	9,504	66,528	1.71

Table 4.5 *cont*.: Summary of proposed groundwater allocation framework including management options and recommended allocation limits (bolded) for Abstraction Categories B and C in water management zones in the Middle Valley catchment. [LSR = mean annual land surface recharge, LSR(LQ) = lower quartile of the annual land surface recharge, MALF = mean annual low flow]

Water management zone	Aquifers	Management objectives	Allocation reference criteria	Groundwater-surface water management zones	Groundwater allocation options	Daily allocation (m^3)	Weekly allocation (m^3)	Annual allocation ($m^3 \times 10^6$)
Taratahi	1: Unconfined + semi-confined	Baseflow depletion: • Springs and wetlands along faultlines	Combined estimated MALF for Masterton and Carterton faultline springs Depletion factor = 0.22	All: Category B to 20 m; Category C >20 m	MALF depletion			
					20%	7,900	55,300	1.41
					30%	11,800	82,600	2.12
					40%	15,700	109,900	2.82
					50%	19,600	137,200	3.53
Fernhill-Tiffen	1: Unconfined-confined	Drawdown management	LSR and LSR(LQ)	All: Category C	LSR(LQ)			
					40%	3,400	23,800	0.61
					50%	4,200	29,400	0.76
					80%	6,700	46,900	1.2
Middle Ruamahanga	1: Unconfined + semi-confined	Baseflow depletion: • Ruamahanga River	Ruamahanga River surface water allocation Throughflow reduction from Parkvale zone: Parkvale (confined) allocation * 0.12	All: Category A	Category A	n/a	n/a	n/a

Table 4.6: Summary of groundwater allocation framework includingmanagement options and recommended allocation limits (bolded) for Abstraction Categories B and C in water management zones in the Lower Valley catchment. [LSR = mean annual land surface recharge, LSR(LQ) = lower quartile of the annual land surface recharge, MALF = mean annual low flow]

Water management zone	Aquifers	Management objectives	Allocation reference criteria	Groundwater-surface water management zones	Groundwater allocation options	Daily allocation (m^3)	Weekly allocation (m^3)	Annual allocation ($m^3 \times 10^6$)
Lake	1: Unconfined 2: Confined aquifers (Q2 + Q4)	1. Baseflow depletion: • Lake Wairarapa • Ruamahanga River • Stonestead Creek • Featherston springs • Tauherenikau River 2. Drawdown	Primary: Mean summer groundwater discharge into Lake Wairarapa. Additional: • Tauherenikau zone springs mean low flow • Throughflow enhancement from adjacent zones • Drawdown	Everywhere: Category B to 15 m >15 m: Category C	Lake Wairarapa GW inflow depletion 15% 20% **25%**	 17,000 27,200 **37,500**	 118,600 190,600 **262,500**	 3.1 4.9 **6.75**
Tauherenikau	1: Unconfined + semi-confined	Baseflow depletion: • Tauherenikau River • Stonestead Creek • Featherston springs • Otukura Stream • Lake Wairarapa	Primary: Total mean summer spring discharge Depletion factor: 0.5	Tauherenikau R. Q1 alluvium and Stonestead Creek capture zone: Category A to 20 m Elsewhere: Category B all depths	Depletion of mean summer spring flow **25%** 35% 50%	 **36,500** 53,500 79,000	 **255,500** 374,500 553,000	 **6.57** 9.63 14.2
Moiki	1: Unconfined	Baseflow depletion: • Ruamahanga River	Ruamahanga River surface water allocation	All: Category A	Category A	n/a (no Categories B or C in this zone so not necessary to calculate groundwater allocation options)		

Table 4.6 *cont.*: Summary of proposed groundwater allocation framework including management options and recommended allocation limits (bolded) for Abstraction Categories B and C in water management zones in the Lower Valley catchment. [LSR = mean annual land surface recharge, LSR(LQ) = lower quartile of the annual land surface recharge, MALF = mean annual low flow]

Water management zone	Aquifers	Management objectives	Allocation reference criteria	Groundwater-surface water management zones	Groundwater allocation options	Daily allocation (m^3)	Weekly allocation (m^3)	Annual allocation ($m^3 \times 10^6$)
Martinborough	1: Semi-confined + confined	Drawdown management	LSR and LSR(LQ)	All: Category C	LSR(LQ)			
					70%	2,600	17,900	0.46
					90%	3,300	23,000	0.59
					100%	3,650	25,500	0.66
					120%	**4,400**	**30,700**	**0.79**
					150%	5,500	38,300	0.99
Lower Ruamahanga	1: Unconfined+ semi-confined	Baseflow depletion: • Ruamahanga River	Ruamahanga River surface water allocation	All: Category A	Category A Add: Lake zone interference	n/a (no Categories B or C in this zone so not necessary to calculate groundwater allocation options)		
Dry River	1: Unconfined + semi-confined	Drawdown management	LSR and LSR(LQ)	All: Category B	LSR(LQ)			
					85%	**3,500**	**24,500**	**0.63**
					100%	4,400	30,800	0.79
					125%	5,300	37,800	0.95
Huangarua	1: Unconfined 2: Semi-confined	Baseflow depletion: • Huangarua River	LSR and LSR(LQ)	Lower Q1 terrace: Category A to 20 m. Elsewhere: Category B	LSR(LQ)			
					45%	**3,600**	**25,200**	**0.64**
					70%	5,400	37,800	0.97
					95%	7,200	50,400	1.29

Table 4.6 *cont*.: Summary of proposed groundwater allocation framework including management options and recommended allocation limits (bolded) for Abstraction Categories B and C in water management zones in the Lower Valley catchment. [LSR = mean annual land surface recharge, LSR(LQ) = lower quartile of the annual land surface recharge, MALF = mean annual low flow]

Water management zone	Aquifers	Management objectives	Allocation reference criteria	Groundwater-surface water management zones	Groundwater allocation options	Daily allocation (m^3)	Weekly allocation (m^3)	Annual allocation ($m^3 \times 10^6$)
Onoke	1: Unconfined 2: Confined	Baseflow depletion: • Tauanui River • Turanganui River Drawdown	Primary: Throughflow recharge Additional: Surface water discharge	Tauanui and Turanganui river valleys: Category A. Main valley: Category C	Throughflow depletion: 30% 40%	 8,700 11,600	 60,900 81,200	 1.57 2.09

5. Implications for monitoring and management

The framework for conjunctive management of groundwater and surface water allocation in the Wairarapa Valley outlined in this report is a significant departure from current practice under the existing RFP (WRC 1999). As a consequence, implementation of the framework presents a range of challenges for GWRC. This section discusses some of the factors which may be involved in adoption of the conjunctive water management approach.

5.1 New and replacement resource consent applications

Adoption of the conjunctive water management framework has significant implications for the management of both new and existing resource consents. In particular, the framework will result in the application of pumping controls (i.e. minimum flow cut-offs) on a significant number of consents which are currently unrestricted as and when they are reviewed or replaced.

GWRC has developed specific guidance to assist the resource consent process (including applications for new and replacement resource consents) until future amendments to current policies for groundwater allocation are adopted in the RFP (WRC 1999). This guidance[17] was developed following the release of the Phase 3 report and is effective from 1 July 2011. In summary this guidance includes:

- Assessment of the conjunctive water management framework with existing water takes for each new water management zone
- Identifies surface water catchments and water management zones where no further water allocation should take place. For all other surface water catchments and water management zones comments are provided for consideration when resource consent applications are processed.
- Guidance for the use of SPASMO-IR – a tool to determine the reasonable water use based on local climate and soil information.
- Consideration minimum flow conditions on groundwater takes with a direct or high degree of hydraulic connection (i.e. Category A or Category B);

5.2 Aquifer testing

Specific guidance has been developed for aquifer testing (including analysis) to assist evaluation of new and replacement resource consent applications, particularly in Category B areas. This guidance[18] include recommendations for pumping rates, test duration, location of observation bores, water level corrections and analysis methodologies similar to those in the recently published Environment Canterbury guidelines[19].

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[17] Guidance for processing resource consents for water take in the Wairarapa (July 2011, Greater Wellington Regional Council)
[18] Aquifer test guidelines for the Greater Wellington region (Pattle Delamare Partners 2012)
[19] http://ecan.govt.nz/publications/Reports/AquiferTestGuidelines2008plusReportExample.pdf

In order to enable reliable assessment of potential stream depletion effects (particularly in Category B areas) the aquifer test guidelines includes guidance on the application of analytical stream depletion estimation methodologies. including recommendations for undertaking stream depletion assessment in non-uniform hydrogeological settings (e.g. in the case of multiple streams or where there is a significant contrast in hydraulic properties such as across the Q1/Q2 boundary) as well as recommendations for determining representative hydraulic parameters (e.g. streambed conductance or representative aquifer transmissivity where multiple aquifer test results are available).

5.3 Management of future surface and groundwater allocation

The conjunctive water management framework results in significant alteration to the management of groundwater and surface water allocation in the Wairarapa Valley. Changes resulting from the adoption of the framework are particularly significant for future surface water allocation policy which will need to address:

- Significantly increased levels of water allocation in many surface waterways due to the inclusion of hydraulically connected groundwater takes within the surface water allocation; and
- Management of baseflow allocation for unregulated groundwater abstraction particularly with regard to how this allocation relates to environmental flows and water levels.

Current levels of surface water allocation will significantly increase on many rivers and streams, if groundwater allocation from Category A (and part Category B) takes is incorporated in calculated surface water allocation as proposed. Development of future surface water allocation policy will therefore need to address situations where this will result in allocation significantly above core allocation specified in the existing RFP. As further discussed in Section 5.5 below, in some cases this over-allocation may occur 'on paper' rather than in terms of actual use.

In considering how to manage a transition from the existing RFP groundwater and surface water allocation provisions to the conjunctive water management framework, it is also important to recognise that the cumulative effects of existing groundwater abstraction are likely to be incorporated (at least to some degree) within existing river flow records. Due to the significant increase in groundwater abstraction across the Wairarapa Valley in recent years these effects are likely to be most evident in data collected over the past five to ten years.

5.4 Policies to support implementation of proposed management framework

Implementation of the conjunctive water management framework is likely to require development of a range of supporting policies that may be included in the current review of the RFP. Such policies may include:

- Where not already established, application of common expiry dates on water permits (for both surface and groundwater takes) within individual water management zones to enable changes to the management of existing resource consents to be applied in a consistent and transparent manner;

- Possible exemptions from pumping regulation (i.e. minimum flow restrictions) for certain types of groundwater takes located in Category A or Category B areas. Such exemptions would enable provision to be made for essential water supplies such as municipal, water scheme and certain industrial uses which support public health and/or animal welfare considerations;

- Establishment of defined reliability of supply criteria for different categories of water use. These criteria could be utilised to assist setting allocation volumes for individual water users as well as to ensure that future allocation does not adversely affect the reliability of supply for existing water users; and

- Policies either reviewing existing consented allocation or facilitating the transfer of allocation between individual water users to improve allocative efficiency. The conjunctive water management framework could be utilised to facilitate the transfer of existing water allocation within individual catchments to improve economic efficiency (e.g. higher value use). For example:

  - Category A groundwater and surface water takes may be interchangeable (provided variations in instantaneous and short-term pumping rates are accounted for);

  - Category C and unrestricted Category B groundwater takes could be transferrable between different aquifers within the same catchment provided baseflow allocation is equal or lower (and an assessment of local effects undertaken); and

  - Category B groundwater subject to regulation could also be proportionally transferred to surface water or Category A or wholly transferred to Category C (subject to assessment of localised effects).

5.5 Environmental monitoring requirements

The conjunctive water management framework focusses on management of the cumulative effects of groundwater and surface water allocation at a catchment scale. As a result, measurement of flow in the lower reaches of Wairarapa's rivers and streams is critical to establish catchment scale environmental flows and water levels and determine compliance with the proposed allocation regime. Flow monitoring is also critical for evaluating the effectiveness of the overall management approach and whether resource management objectives have been achieved.

At the current time, for a range of historical (e.g. flood warning) and practical (e.g. stable sections) reasons, flow monitoring in the Wairarapa Valley tends to be concentrated in upper catchment areas close to the points where the main rivers emerge from the Tararua Range or Eastern Hills onto the Wairarapa Valley. However, the main areas of groundwater/surface water interaction and critical ecological effects tend to occur as the rivers traverse the Wairarapa Valley. As a consequence, current monitoring is not particularly well-suited to the management of water allocation and associated environmental effects.

It is therefore recommended that GWRC undertake a review of its existing hydrological monitoring network to support implementation of the conjunctive water management framework. Such a review may focus on collection of additional flow information either by way of permanent or temporary flow monitoring sites in lower river reaches or through an increased frequency of gaugings in these areas to enable correlation with established flow monitoring sites.

Field investigations required to support implementation of the conjunctive water management framework include the measurement of streambed conductance values in representative reaches of rivers and stream in the Wairarapa Valley. These investigations may be particularly important in smaller spring-fed tributaries (in Category B areas) to provide reliable estimates of streambed conductance values to inform analytical stream depletion assessments.

5.6 Aligning allocation with actual use

At the current time water permits issued by GWRC authorising groundwater abstraction in the Wairarapa Valley specify maximum instantaneous and daily rates of take and set a maximum (volumetric) seasonal allocation. However, both metered water use data and irrigation abstraction modelling undertaken by Gyopari and McAlister (2010 a, b and c) suggest that actual groundwater abstraction (in terms of peak abstraction rates and seasonal usage) is significantly lower than consented volumes. Data collected through various metering studies typically show peak (weekly) water usage typically ranges between 60% and 75% of the maximum consented rate. However, on an annual basis seasonal water usage is generally much lower at around 30% of the total consented volume.

The mismatch between consented allocation and actual use significantly reduces allocative efficiency. This situation has potential implications for efficient and sustainable management of groundwater and surface water resource including:

- Where fixed volumes of water are available for allocation (either in terms of groundwater or surface water), allocation of water to individual users in excess of their ‘reasonable’ needs can prevent additional users accessing the available resource;

- The potential environmental effects of groundwater abstraction (such as potential stream depletion effects) may be significantly over-estimated when based on consented volumes;

- As water resources approach or reach full allocation incentives may increase for existing users to transfer the unused portion of their allocation in accordance with s136 of the RMA. This may result in unanticipated environmental effects as cumulative water use increases, particularly if existing allocation limits do not adequately incorporate uncertainty regarding resource availability and interconnection between surface and groundwater. Increased utilisation of consented allocation may also result in a reduction in supply reliability for existing resource users if this has not already been factored into existing allocated volumes.

GWRC has recently acquired a version of the SPASMO-IR[20] model which enables calculation of water requirements for a range of crop types under nominated climate conditions. Calculations of potential water requirements should incorporate the concept of reliability of supply whereby sufficient water is allocated to meet potential demand under a given scenario. GWRC has recommended that sufficient water is allocated to satisfy crop demand 9 years out of 10 (i.e. providing 90% reliability of supply).

5.7 Water metering

Actual water use data are critical for successful water resource management. Improved access to quality-assured water metering data in the Wairarapa Valley will be needed to both support and monitor the implementation of the framework as well as better understand the disparity between consented and actual use (discussed in Section 5.5). National regulations for water metering support GWRC initiatives that have been in place since around 2000. GWRC has developed a Compliance Monitoring Strategy for water take consents[22]. This strategy outlines the water metering standards for various catchments and aquifers including where real time telemetry monitoring systems are required

[20] SPASMO-IR is short for Soil Plant Atmosphere System Mode for Irrigation, a computer-based tool developed for GWRC by Plant and Food New Zealand. SPASMO-IR can be used to determine various crop water requirements to help enable efficient use.
[22] Compliance Monitoring Strategy – Water Takes. (July 2011, Greater Wellington Regional Council)

6. Summary

The groundwater resources of the Wairarapa Valley sustain freshwater ecosystems and support important economic and social values and meet water demands for domestic, municipal, agricultural and industrial purposes. Rapidly increasing pressure on water resources over the past decade led to this review of existing water allocation methodology to ensure that both groundwater and surface water resources are sustainably managed.

The framework for conjunctive management of groundwater and surface water allocation in the Wairarapa Valley outlined in this report provides for:

1. Designation of spatially defined management units which are assigned volumetric allocation limits that take account of the potential effects of groundwater abstraction on baseflow at a catchment scale; and

2. Active management of those groundwater abstractions which have a direct or immediate effect on the surface water environment which can be effectively mitigated by the application of management controls (such as minimum flow cut-offs).

In order to implement these objectives, a three-tier management approach establishes a framework for managing groundwater abstraction according to its potential impact on surface water. The framework allows differentiation between those groundwater takes which have a direct and immediate effect on surface water from those where there may be a considerable lag between pumping and resulting effects on surface water, based on three nominal categories of hydraulic connection. The framework effectively establishes a three-dimensional framework for the management of groundwater abstraction based on geographic location and depth criteria which vary according to the local hydrogeological environment and resulting connectivity between surface and groundwater. The hydraulic connectivity categories proposed are:

Category A: Direct hydraulic connectivity

Category A includes areas of the hydrogeological system that exhibit direct connectivity with surface water and typically encompasses the highly permeable Q1 gravel aquifers that occur along the riparian margins of the main river systems. In these areas both physical monitoring and modelled pumping scenarios indicate a high degree of connectivity with surface water. Due to the high degree of hydraulic connection, stream depletion effects occur shortly following the commencement of groundwater abstraction and rapidly increase to a level close to the overall pumping rate. As a consequence, a high proportion of the overall volume of groundwater pumped effectively represents induced flow loss from local surface waterways.

Due to the immediacy of impact, groundwater abstraction from Category A areas can be considered as being analogous to direct surface water abstraction in terms of the magnitude and temporal response of stream depletion effects. Groundwater abstraction from Category A areas are managed in terms of the environmental flow and water level regimes (i.e. minimum flows and core allocations) established for relevant hydraulically connected surface waterbodies. At the time of writing, minimum flows and allocation levels for rivers and streams are being reviewed by GWRC.

Category B: High hydraulic connectivity

Category B includes those areas of the hydrogeological system where groundwater abstraction may potentially result in significant impacts on surface water but where pumping regulation does not always provide an effective option for mitigating direct stream depletion effects. Category B effectively represents the transition between direct and indirect stream depletion effects where it may be appropriate to manage groundwater takes in terms of either surface water or groundwater allocation policies depending on localised factors (e.g. local aquifer hydraulic parameters, abstraction rate and location of pumping with respect to surface waterbodies).

The Category B classification applies to all groundwater takes with an average weekly abstraction rate of >5 L/s in nominated areas (takes <5 L/s are included in the groundwater allocation for the relevant water management zone). Takes in Category B areas are subject to minimum flow policies established for relevant hydraulically connected surface waterbodies where assessment indicates stream depletion effects are sufficiently high (q/Q>0.6 and/or >10 L/s). For those takes subject to minimum flow controls the calculated stream depletion effect are counted as part of the total allocation for hydraulically connected surface waterbodies, with the balance counted as part of the groundwater allocation for the relevant water allocation zones.

Category C: Moderate to low hydraulic connectivity

Category C includes those areas of the hydrogeological system where groundwater abstraction may contribute to an overall reduction in baseflow discharge at a catchment scale but where active regulation of groundwater pumping does not mitigate effects on surface water.

For each water management zone options and recommended groundwater allocation limits are presented based on the outputs of abstraction scenarios run on the numerical groundwater flow models developed for each catchment (Gyopari and McAlister 2010 a, b and c). These models simulate the cumulative effects of groundwater abstraction in terms of surface water depletion, aquifer drawdown, and changes in cross-zone throughflow dynamics. This information provides the basis for developing sustainable groundwater allocation limits for each water management zone. Where appropriate the recommended groundwater allocation limits are referenced to the potential cumulative effect on baseflow at a sub-catchment scale in relevant hydraulically connected surface waterbodies.

The framework for conjunctive management of groundwater and surface water allocation in the Wairarapa Valley outlined in this report is a significant departure from current practice under GWRC's existing Regional Freshwater Plan. While there are a number of challenges to successful implementation of the management framework, it offers a potential means to integrate the management of groundwater and surface water resources and provide an improved basis for sustainable allocation .

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Appendix A

Appendix A: Technical and policy background

In most environmental settings groundwater and surface water are interconnected and interchangeable components of the hydrological system. However, the rate and magnitude of interaction between these elements can exhibit significant spatial and temporal variability. For example, one key distinction between groundwater and surface water is the timescale of water movement. While water is typically exported from a catchment via surface runoff within days of a rainfall event it may take years or even decades for water infiltrating through the soil zone to flow through an aquifer system to its final discharge point. Consequently, a good understanding of interaction between groundwater and surface water processes, both in a spatial and temporal context, is required to enable effective and integrated water resource management.

A.1 Stream-aquifer interaction

The following section provides an introduction to some of the key concepts related to the interaction between surface and groundwater resources.

A.1.1 Hydraulic connectivity

The concept of *hydraulic connectivity* describes the degree of interconnection between groundwater and surface water which ultimately determines the magnitude of flow exchange likely to occur in any given hydrogeological setting.

Groundwater and surface water bodies can be regarded as exhibiting a high degree of hydraulic connectivity if water can readily flow from a surface water body into, or out of, a hydraulically connected groundwater resource. Examples of highly connected water resources include:

- Shallow unconfined gravel aquifers which are recharged by flow loss from overlying rivers and streams; and

- Streams where groundwater inflow provides a significant baseflow input during low flow conditions.

Stream-aquifer systems may be characterised as exhibiting low (or poor) hydraulic connectivity if the movement of water between these systems is limited. Examples of water resources exhibiting a low degree of hydraulic connectivity include:

- Streams separated from an underlying aquifer by intervening low permeability sediments; and

- Deep confined aquifers where the rate of vertical leakage to and from overlying groundwater and connected surface water resources is low.

Natural stream-aquifer systems may range from highly to poorly connected depending on local topography, geology and climate conditions. As a result, the degree of connectivity between surface and groundwater may vary across a catchment reflecting local conditions. Stream-aquifer connectivity may also vary over time in response to seasonal variation in relative water levels.

In a planning context water bodies can be classified in terms of hydraulic connectivity if the movement of water between groundwater and surface water has implications for water quantity (and/or quality) management over a specified planning timeframe (after Evans 2007).

A.1.2 Gaining and losing streams

In situations where rivers or streams are hydraulically connected to an adjacent aquifer, water may flow into, or out of, the aquifer system according to the relative hydraulic gradient. Where groundwater levels are higher than river stage groundwater will discharge to the stream. In this case the stream is defined as a *gaining stream* and the groundwater discharge termed *baseflow*. Conversely, where surrounding groundwater levels are lower than stream stage, water may flow from the stream into the surrounding aquifer. In this case the stream is defined as a *losing stream* and the recharge to groundwater commonly referred to as *stream leakage*. Figure A1 below shows an example of a *gaining stream* while Figure A2 illustrates a *losing stream*.

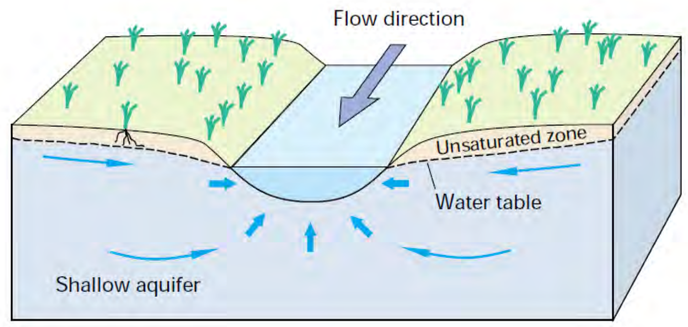


Figure A1: Gaining Stream (Winter et al. 1998)

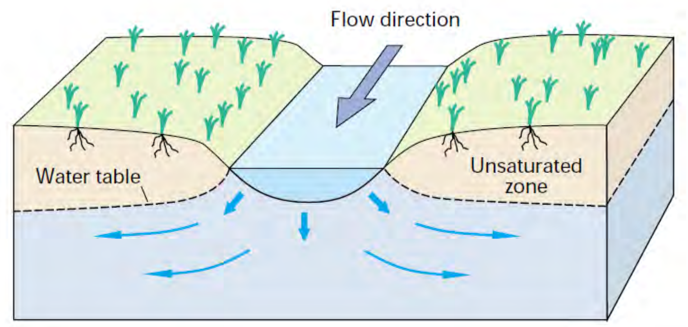


Figure A2: Losing Stream (Winter et al. 1998)

Within any given catchment, a stream may have a number of reaches over which it is alternately gaining or losing. The location and extent of these gaining and losing reaches may change over time in response to changes in relative river stage and groundwater levels. These changes may result from a number of factors including climate variability, aggradation or degradation of river bed level as well as changes in groundwater levels due to seasonal variations in aquifer storage or groundwater abstraction.

A stream may also be classified as *disconnected* where there is a zone of unsaturated material between the base of the stream and the underlying water table (such streams are also commonly referred to a *perched*). As shown in Figure A3, although water may infiltrate vertically from the stream into the underlying water table, there is no direct hydraulic connection between the stream and aquifer.

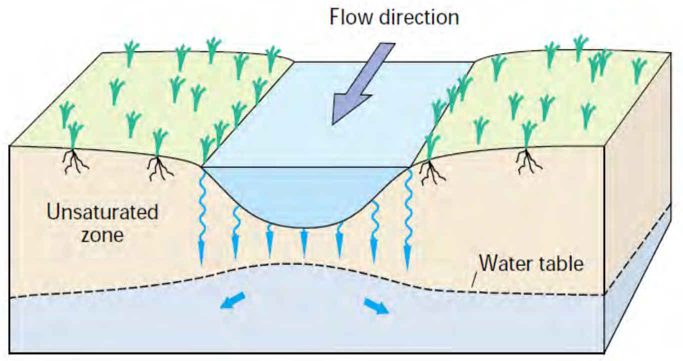


Figure A3: Disconnected (or perched) stream (Winter et al. 1998)

A.1.3 Effects of groundwater abstraction on stream flow

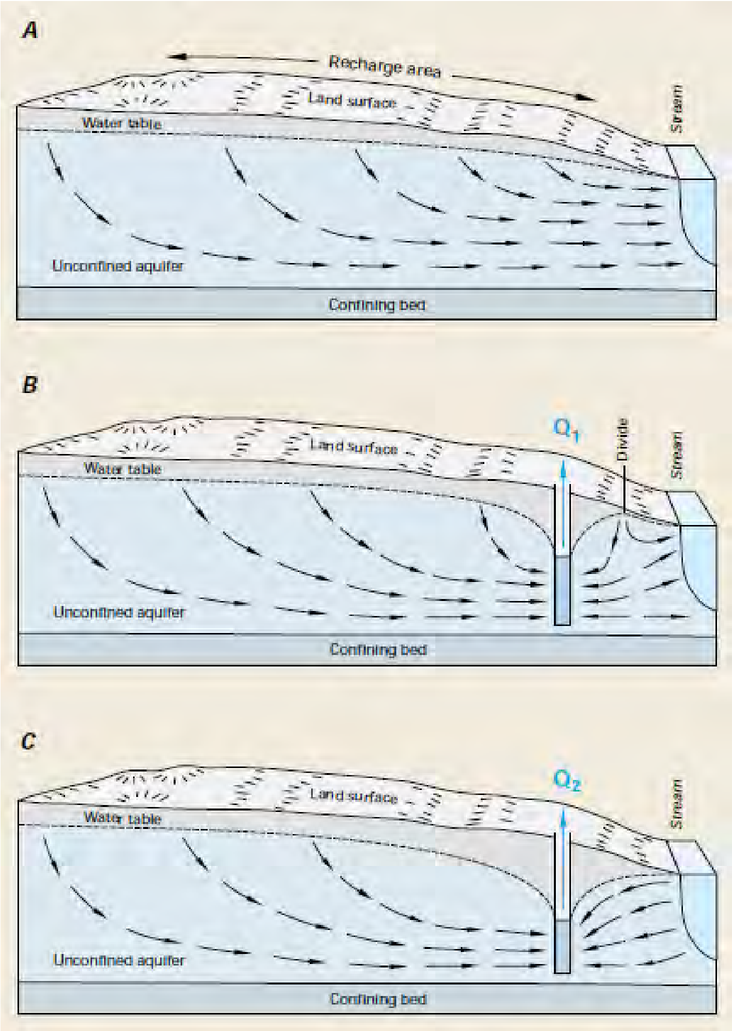
Drawdown of groundwater levels resulting from abstraction has the potential to impact on stream flow in hydraulically connected surface waterbodies. In the case of a losing stream, drawdown resulting from groundwater abstraction may increase the gradient between the stream and aquifer resulting in an increase in stream leakage. An increase in the natural rate of stream leakage resulting from groundwater abstraction is referred to in this report as *direct stream depletion*. The rate of direct stream depletion increases progressively as the groundwater levels adjacent to the stream decline as a result of groundwater pumping (i.e. the relative hydraulic gradient increases).

In the case of a gaining stream the effect of groundwater abstraction can be twofold. The initial effect of the drawdown will be to reduce groundwater baseflow discharge (termed *indirect stream depletion* or *baseflow depletion* in this report). It is important to differentiate this effect from direct stream depletion, as during the initial stages of pumping, there is a groundwater divide (i.e. a high point in the piezometric surface) between the pumping well and the stream. This means the reduced baseflow discharge is not due to direct removal of water from the stream but instead results from a reduction in the hydraulic gradient across the aquifer to the stream. Thus, indirect stream depletion refers to the situation where groundwater abstraction effectively intercepts a portion of aquifer throughflow that would otherwise have been discharged to a surface water body.

Over time, the extent of drawdown resulting from groundwater pumping will expand and eventually reach the stream. If the pumping rate is high enough, or pumping continues for a sufficient period, the magnitude of drawdown may be sufficient to drop the surrounding groundwater level below stream stage. In this case baseflow discharge ceases and the stream becomes a losing reach discharging water to the surrounding aquifer.

The transition from a gaining stream to a losing stream is illustrated in Figure A4. Under the natural conditions in Diagram A, groundwater is recharged from the land surface and flows through the aquifer following the natural topographic gradient and ultimately provides baseflow discharge to the stream. In Diagram B, groundwater abstraction results in a localised decline in the natural water table which reduces the piezometric gradient toward the stream thereby reducing baseflow discharge. In

Diagram C, the drawdown in groundwater levels resulting from abstraction is sufficient to reverse the natural hydraulic gradient and the stream loses water to the aquifer system.



(Source: USGS 1998)

Figure A4: Schematic illustration of the reduction in baseflow discharge and direct stream depletion occurring in a gaining stream in response to groundwater abstraction

In summary, groundwater abstraction from an aquifer system hydraulically connected to adjacent surface waterways has the potential to impact on stream discharge in two ways:

- Increased aquifer recharge (direct stream depletion effects); and
- Decreased baseflow discharge (indirect stream depletion effects).

A.1.4 Timing and magnitude of groundwater abstraction effects on surface water

Scaling issues, both of space and time are a significant technical challenge in the assessment and management of the effects of groundwater abstraction on streamflow.

Figure A5 illustrates the effect of the spatial location of groundwater abstraction on the calculated rate and duration of stream depletion effects. The example shows a series of curves representing the calculated direct stream depletion effect (in terms of the percentage of groundwater abstraction rate) for a bore pumped at a constant rate for a period of 150 days at varying distances from a stream[23].

The curves show that for a bore located adjacent to a hydraulically connected surface waterway stream depletion occurs shortly after pumping commences and rapidly approaches the rate of groundwater abstraction. However, as the distance between the pumped bore and stream increases, the overall magnitude of stream depletion reduces with a significant time lag between pumping and resulting effects. This effectively results in a trade-off between the overall magnitude of stream depletion and the ability to control effects in a temporal sense.

This trade-off between the magnitude of stream depletion and temporal response to changes in pumping rate presents a major challenge in terms of managing the overall effect of groundwater abstraction on surface water discharge. For example, although groundwater takes with a moderate or low connectivity to surface water may have a lower overall effect (in terms of the proportion of groundwater abstraction effectively derived from surface water), they are less amenable to control by pumping regulation. Therefore, it must be accepted that if groundwater abstraction is to occur away from the immediate surrounds of river and streams there will be an effect on stream flow that cannot effectively be controlled or mitigated during periods of low flow.

One other important point to note is that, for the example shown in Figure A5, if the x-axis was extended sufficiently the area under the respective curves during and subsequent to pumping would effectively be equal. Thus, in an idealised aquifer system, although the location of pumping may alter the timing and instantaneous magnitude of stream depletion it does not alter the overall cumulative effect.

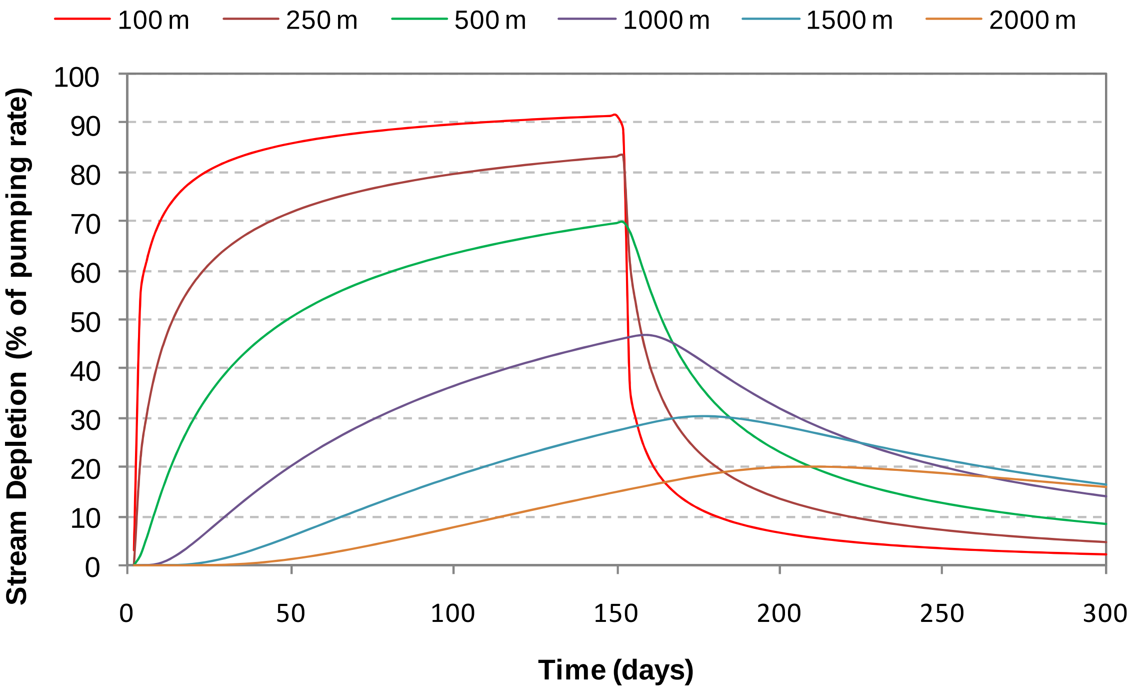


Figure A5: Calculated stream depletion resulting from a bore located at varying distances from a hydraulically connected stream

23 The example assumes constant hydraulic properties and pumping rate and is calculated utilising an analytical stream depletion equation.

The time lag between groundwater abstraction and resultant stream depletion effects complicates management of groundwater takes that have a limited connectivity to surface water. In this case impacts on stream flow, either resulting from direct stream depletion effects or through changes in baseflow discharge, may occur over a relatively long timescale and cannot effectively be mitigated by pumping controls.

A.2 Existing approaches to the management of stream depletion

The following section reviews a range of approaches that have been adopted in New Zealand and overseas for the management of stream depletion effects resulting from groundwater abstraction. The approaches adopted can be classified into two basic types:

- Arbitrary classification: classification and management of potential stream depletion based on arbitrary set-back distances or abstraction rates; and

- Zonal management: classification and management of potential stream depletion effects based on classification of individual groundwater takes according to arbitrarily defined hydraulic connection categories.

A.2.1 New Zealand

Hawke's Bay Regional Council

The Hawke's Bay Regional Resource Management Plan recognises the potential for shallow groundwater abstraction to impact on rivers, streams and lakes. In order to manage these potential effects Policy 33 identifies that any shallow groundwater take within 400 metres of a surface water body will be managed as if it were a direct surface water take unless a scientific assessment has been undertaken to establish potential stream depletion effects are no more than minor. Takes located greater than 400 metres from a surface water body may also require a stream depletion assessment depending on hydrogeological characteristics, and may be managed as an equivalent surface water take.

Environment Southland

Policy 29 of the Regional Water Plan for Southland establishes a zonal management approach based on arbitrarily defined hydraulic connection classifications. The classification of hydraulic connection is based on a calculated percentage of groundwater abstraction (q/Q) derived from surface water after a nominated pumping interval (either 7 or 150 days).

Table A1 provides an outline of the effect of Policy 29. Groundwater takes assessed as having a direct hydraulic connection are subject treated as equivalent surface water abstractions and subject to the environmental flow regime (including minimum flow and flow allocation) for the relevant surface water body. Groundwater takes assessed as having a high degree of hydraulic connection are subject to minimum flow restrictions and the calculated stream depletion effects counted as part of the total allocation for relevant surface water bodies. Takes assessed as having a moderate hydraulic connection are not subject to minimum flow restrictions but the calculated stream depletion component is counted as part of the relevant surface water allocation. Finally, those groundwater takes classified as having a low degree of hydraulic connection are managed independently of surface water environmental flow and water level regimes.

Table A1: Environment Southland policy for classification and management of direct stream depletion effects

Hydraulic connection	Classification	Management
Direct	q/Q[a] >0.8 after 7 days pumping	Managed as an equivalent surface water take
High	q/Q <0.8 after 7 days pumping q/Q >0.6 after 150 days pumping at average seasonal rate	Subject to relevant minimum flow cut-off(s) Calculated stream depletion effect counted as allocation for relevant surface water body
Moderate	q/Q <0.6 but >0.3 after 150 days pumping at the average seasonal rate or Calculated stream depletion effect >5 L/s	Calculated stream depletion effect counted as allocation for relevant surface water body
Low	Takes not classified as having a direct, high or moderate hydraulic connection	Managed in terms of groundwater allocation only

[a] The potential rate of stream depletion is commonly referred to in terms of q/Q which is the ratio of direct stream depletion (q) to the overall pumping rate (Q).

Figure A6 shows a geographical representation of the zonal management approach defined by the Environment Southland stream depletion effects policies. The graphic shows the concentric distribution of the hydraulic connection categories (subject to different minimum flow and flow allocation criteria) around the river channel, defined on the basis of aquifer hydraulic properties.

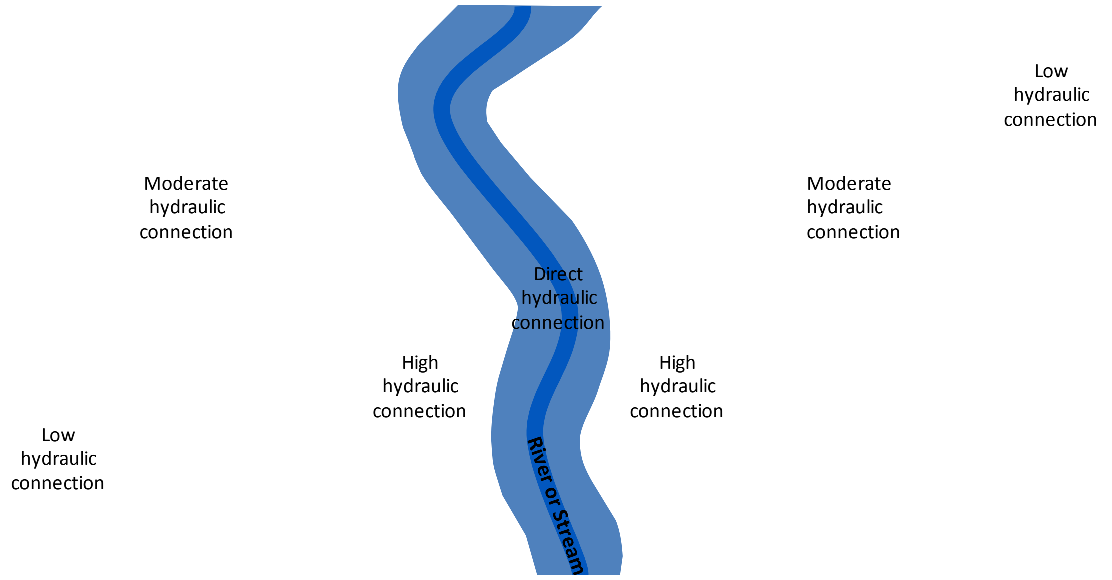


Figure A6: Schematic illustration of the spatial distribution of hydraulic connection categories specified in the Environment Southland Water Plan

Environment Canterbury

Policy WQN8 of the Environment Canterbury Proposed Natural Resources Regional Plan (NRRP) outlines a framework for the management of stream depletion in the Canterbury Region. Groundwater takes are classified according to nominated categories of hydraulic connection and minimum flows and flow allocation managed in a similar manner to that specified in the Environment Southland Regional Water Plan.

Otago Regional Council (ORC)

Plan change 1C to the *Regional Plan: Water for Otago* has recently added provisions relating to the management of stream depletion effects. These policies utilise a combination of two approaches to the management of direct stream depletion effects. Firstly, groundwater takes from riparian aquifer systems listed in plan schedule 2C (or within 100 metres of any surface water body) are included in the primary allocation defined for the relevant surface water bodies (i.e. managed as equivalent surface water takes). Secondly, an arbitrary methodology is outlined in a schedule 5A to identify if:

- an individual groundwater take has to be assessed for stream depletion effects; and
- to calculate the potential magnitude of the effect.

The calculated stream depletion effect is then counted as part of the primary allocation for the relevant surface water body. The criteria for determining which groundwater takes require assessment for stream depletion effects is based on an arbitrary relationship developed between pumping rate and distance from the surface water body as illustrated in Figure A7 .

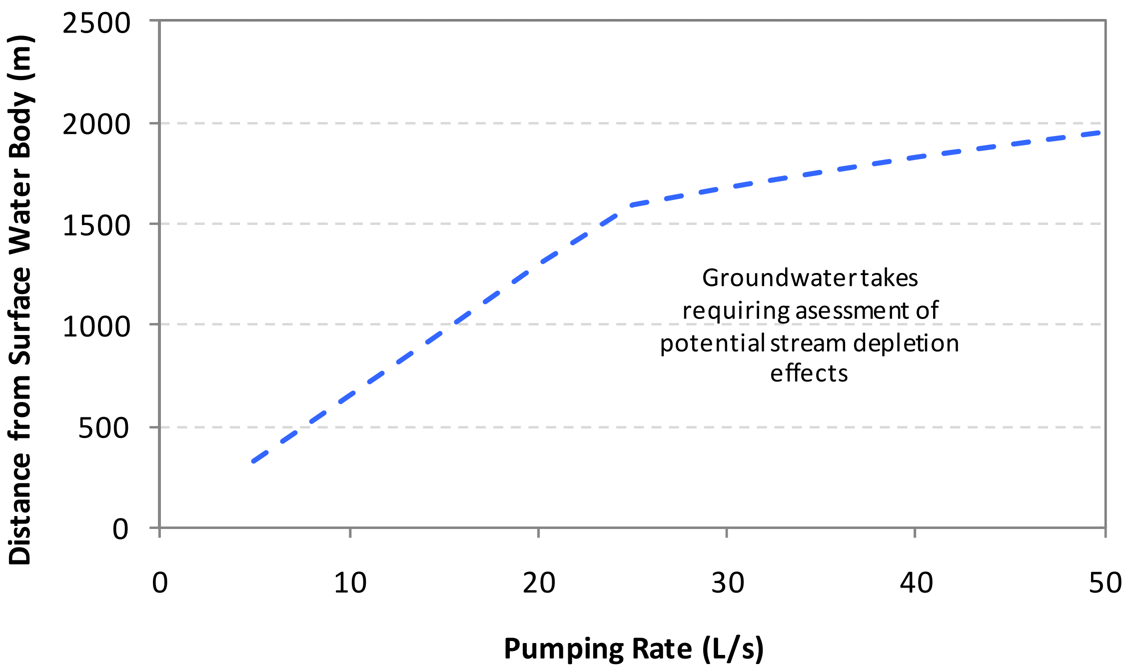


Figure A7: Schematic illustration of criteria specified in the ORC Water Plan used to determine if an individual groundwater take requires assessment of potential stream depletion effects

A.2.2 Australia

Evans (2007) proposed a framework for the management of stream depletion effects in Australia based on the concept of zonal management. The proposed framework was based on an extensive evaluation of potential options for managing stream depletion effects in Australia utilising the concept of hydraulic connectivity. The resulting classification illustrated in Figure A8 identifies four management zones based on the time lag response in stream depletion effects resulting from groundwater abstraction. These zones and recommended management approaches are summarised as:

Zone 1 – Very short time lag

Zone 1 applies close to streams where there is a major interference with stream flows and the delay between groundwater abstraction and stream flow depletion is short (e.g. within one week). All groundwater takes should be managed on the basis of surface water extraction rules.

Zone 2 – Short time lag

Zone 2 applies to all groundwater use that could impact on stream flows over the critical low flow period of the stream during the planning timeframe. Typically, flow depletion from extraction is detected within three months. Short-term restrictions on groundwater use may be emplaced based on triggers such as minimum groundwater levels.

Zone 3 – Medium to long time lag

Zone 3 would apply to those groundwater users with impacts on stream flow occurring over the long-term (in the order of 1 to 50 years). This would often incorporate all groundwater users in a surface water catchment, with the exception of those in Zones 1 and 2.

Zone 4 – Very long time lag

Zone 4 would apply where there is no discernable impact of groundwater use on streamflow. This zone would not necessarily be a set distance from the stream, but would apply to particular hydrogeological conditions, for example deep confined or coastal aquifers.

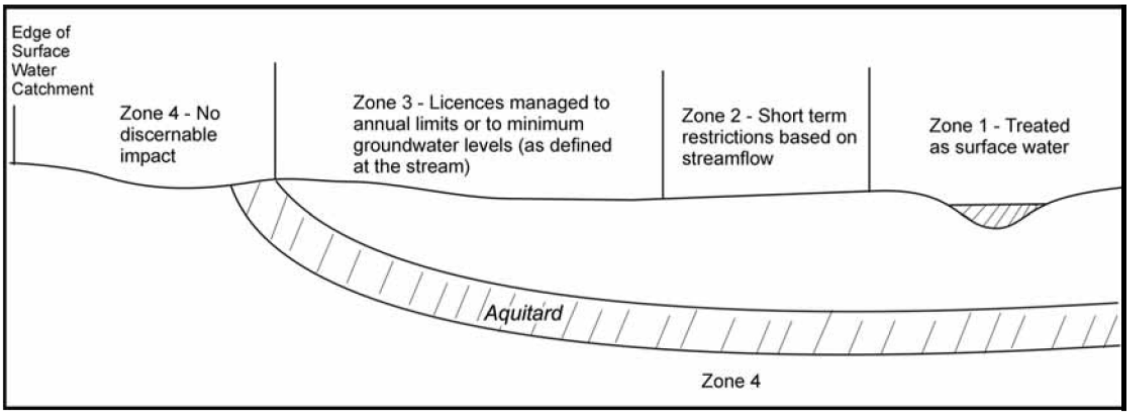


Figure A8: Proposed framework for the management of stream depletion effects in the Australian context (Evans 2007)

A.2.3 USA

Water rights law in the US is complex and often litigious with individual states adopting quite different approaches to the management of water allocation. In the western states, water management is typically governed by the doctrine of prior appropriation which follows the principle of '*first in time, first in right*' and seeks to preserve the rights of initial water users (termed *senior appropriators*) against effects from subsequent users (termed *junior appropriators*). In the eastern states water management typically follows the principle of riparian rights which confers the right for landowners to make '*reasonable use*' of the water resources adjoining their property.

Application of prior appropriation or riparian rights to water management in the US means that many of the policy frameworks adopted for the management of stream depletion effects are not directly relevant in the New Zealand context. However, many of the technical methodologies used to assess the individual or cumulative effects of groundwater abstraction on stream flow have direct applicability. In this regard it is noted that historical approaches based on arbitrary setback distances (commonly termed *brightlines*) have generally been replaced in more recent times by analytical assessment methodologies (commonly utilising the concept of a *stream depletion factor*[24]) or increasingly by numerical modelling techniques which incorporate both groundwater and surface water flow.

A.3 Managing cumulative stream depletion effects

In New Zealand, sustainable groundwater allocation limits are typically established for individual aquifer systems in terms of a maximum volume of groundwater able to be abstracted on an annual basis in order to ensure environmental values associated with the aquifer system are maintained above nominated thresholds. These environmental values are generally defined in terms of localised effects such as maintaining discharge in spring-fed streams, ensuring aquifer storage volumes are maintained or avoiding saline intrusion into coastal aquifers. Local effects of groundwater abstraction are generally managed by application of pumping controls such as allocation limits and minimum groundwater levels.

As described in Section A.2 a number of regional councils across New Zealand have established policies which attempt to manage direct stream depletion effects from groundwater abstraction by a combination of:

- Application of pumping regulation based on surface water minimum flows to groundwater takes assessed as having a high degree of hydraulic connection to surface water; and

- Accounting for a portion of groundwater abstraction as part of the overall allocation for hydraulically connected surface water bodies.

However, in order to manage cumulative effects of groundwater abstraction on surface water it has to be recognised that groundwater takes with a moderate or low degree of hydraulic connectivity also contribute to the cumulative reduction in river or stream baseflow at a catchment scale. These effects are particularly evident in inland basins (such as the Wairarapa and Upper Hutt Valleys) where all water (groundwater or surface water) effectively exits the basin via surface water flow at a downstream point.

This situation is concisely summarised by Bidwell (2003) who noted:

Any abstraction from an aquifer has an effect that eventually propagates throughout the whole aquifer. This effect may be a lowering of piezometric levels or induced recharge from a river. The effect from any one well may be infinitesimal in terms of practical measurement, but the cumulative long-term effects of many wells can be very significant. The result is that every user of groundwater from an aquifer is a contributor to environmental effects such as reduction in low flows in streams or salt-water intrusion, which are determined by natural outflow to surface waters at the whole-aquifer scale.

24 Stream depletion factor is based on the hydraulic properties of the aquifer system and generally describes the overall magnitude and lag between groundwater abstraction and resulting effects on surface water.

Appendix B

Appendix B: Groundwater–surface water interaction in the Wairarapa Valley

This section describes the natural interaction between groundwater and surface water in the Wairarapa Valley based on available geological, hydrogeological, hydrological and water quality information. The information presented draws heavily on the detailed hydrogeological assessments undertaken by Gyopari and McAlister (2010a, 2010b and 2010c) to develop a conceptual model of groundwater-surface water interaction in the Wairarapa Valley. This conceptual model was utilised to develop the recommendations for a planning framework to enable the integrated management of surface and groundwater resources outlined in the main body of this report.

B.1 Geology and hydrostratigraphy

The Wairarapa Valley is a geologically complex area where the effects of structural deformation (faulting and folding) exert a significant influence on the overall hydrogeological setting. The following section provides an overview of the geological and hydrostratigraphic setting in the Wairarapa Valley, particularly those aspects that influence the potential for groundwater/surface water interaction. A more detailed description of the geology of the Wairarapa Valley is presented in Begg et al. (2005) and detailed assessment of the hydrogeological setting described in Gyopari and McAlister (2010a, 2010b and 2010c).

B.1.1 Geology

The Wairarapa Valley groundwater basin occupies a NE-SW trending structural depression approximately 110 km long by 15 km wide extending from north of Masterton to the south coast at Lake Onoke. The basin is bounded to the west by Mesozoic greywacke basement which forms the Tararua Range and to the east by late Tertiary/early Pleistocene marine strata (predominantly mudstone).

The Wairarapa Valley is infilled with a sequence of fluvial sediments deposited, and locally reworked, during successive Quaternary glacial and interglacial periods. The accumulation of these alluvial materials was influenced by folding and faulting associated with structural deformation along the active plate boundary which crosses the lower North Island. This deformation resulted in the accumulation of alluvial sediments within actively subsiding sedimentary basins but also complicated the geological setting due to the widespread disruption of the sedimentary sequence by contemporaneous fault movement, which displaced blocks of uplifted basement against the younger sedimentary sequence.

Table B1 presents a summary of the stratigraphic succession within alluvial deposits infilling the Wairarapa Valley. These deposits are of variable thickness extending to depths greater than 150 metres below ground in the Lake Wairarapa basin but typically less than 50 metres thick across the remainder of the valley. Figure B1 shows a simplified geological map of the Wairarapa Valley.

Table B1: Stratigraphic sequence in the Wairarapa Valley (after Gyopari and McAlister 2010a, 2010b and 2010c)

Relative age	Name	Material	Depositional environment	Absolute age (1000s of years)	Map symbol
Holocene		Mud & silt	Estuarine, lacustrine	0-7	Q1m Q1s
Holocene		Gravel & sand	Alluvial	0-10	Q1a
Late Quaternary (*Late Otarian*)	Waiohine	Gravel & sand	Alluvial	10-25	Q2a
Late Quaternary (*Middle Otarian*)	Ramsley	Gravel & sand	Alluvial	25-50	Q3a
Late Quaternary (*Early Otarian*)	Waipoua	Gravel & sand	Alluvial	50-70	Q4a
Late Quaternary (*Kaihinu Interglacial*)	Francis Line	Mud, silt, sand & minor gravel	Swamp, lacustrine	70-125	Q5m
Late Quaternary (*Kaihinu Interglacial*)	Eparaima	Sand, some gravel	Marginal marine	70-125	Q5b
Middle Quaternary (*Waimea Glacial*)	(Equivalent to Moera Gravel in Lower Hutt)	Gravel & sand	Alluvial	125-186	Q6a-Q8
Middle Quaternary	Ahiaruhe	Gravel, sand, silt, loess, tephra	Alluvial, swamp	>186-500	mQa
Early Quaternary	Te Muna	Gravel, sand, silt, loess, tephra	Alluvial, swamp	c. 500-1000	eQa

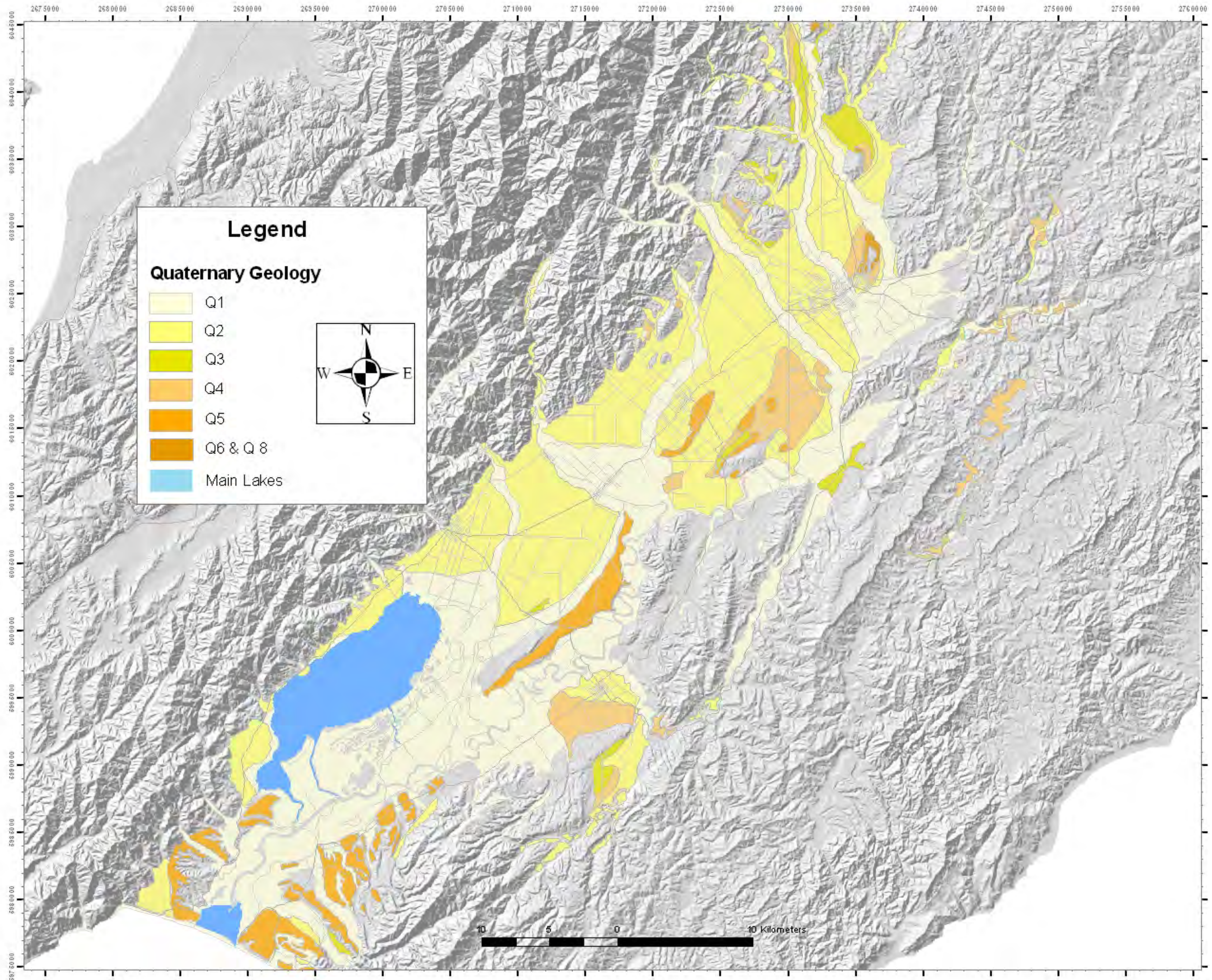


Figure B1: Simplified geological map of the Wairarapa Valley (Begg et al. 2005)

B.1.2 Hydrostratigraphy

Gyopari and McAlister (2010a, 2010b and 2010c) present detailed assessments of the geology and hydrostratigraphy of the Wairarapa Valley. The following section summarises this information to identify the main hydrostratigraphic and geological features which define and influence the hydrogeological setting in the Wairarapa Valley, particularly with regard to interaction between surface and groundwater.

Alluvial fan deposits

Large alluvial fans have developed where the major river systems emerge from the surrounding hills into the Wairarapa Valley. These include the extensive alluvial fans deposited by the Ruamahanga, Waingawa, Waiohine and Tauherenikau rivers as well as those associated with some of the smaller river systems including the Mangatarere Stream and Waipoua River. These alluvial fans extend from the Tararua foothills eastward across the valley. Several smaller alluvial fans also extend into the Wairarapa Valley from eastern catchments including those of the Whangaehu, Huangarua, Tauanui and Turanganui rivers. These alluvial fan deposits comprise the present-day landform throughout much of the Wairarapa Valley.

The alluvial fan deposits represent accumulation of Q2 to Q8 gravels on an active depositional surface. These gravel deposits are typically poorly sorted with significant amounts of sand and silt present within the gravel matrix, although improved sorting and channelisation is evident in some distal areas. The alluvial fan deposits associated with the major river systems form relatively extensive, moderate to low permeability stratified aquifer systems which extend across much of the western side of the Wairarapa Valley. Groundwater is found pervasively throughout these deposits where discrete layers of water bearing gravels are typically interspersed with lower permeability intervals forming a stratified aquifer system which may exhibit semi-confined (leaky) characteristics at depth due to the presence of the intervening lower permeability materials.

In terms of groundwater/surface water interaction, the most notable feature on the alluvial fan areas are deposits of recent Q1 gravels which have formed where the main river systems have reworked the older alluvial fan deposits since the last glacial period. These gravel deposits are typically restricted to the riparian margins of the major rivers and their lateral extent is often marked by prominent alluvial terraces which mark the lateral extent of postglacial river entrenchment. The Q1 gravels form shallow unconfined aquifers generally less than 15 metres in thickness which are highly permeable and exhibit a high degree of connectivity with surface water.

Alluvial sub-basins

Alluvial sub-basins occur in the Wairarapa Valley where structural deformation has allowed the accumulation of successive deposits associated with Quaternary glacial and interglacial cycles. In these areas, active subsidence has allowed differentiation of more permeable interglacial alluvial deposits (Q4, Q6 and Q8) from the intervening clay and silt dominated glacial deposits (Q3, Q5 and Q7) to form a sequence of semi-confined aquifers. Individual alluvial sub-basins are identified in the Te Ore Ore, Parkvale, Carterton and Lake Wairarapa areas. These individual sub-basins may be structurally complex due to internal deformation associated with faulting and folding.

Groundwater within the alluvial sub-basins typically exhibits limited direct interaction with surface water. However, vertical leakage induced by groundwater abstraction does have the potential to influence the water balance of overlying unconfined aquifers, by reducing discharge to local spring-fed stream and wetlands or intercepting a portion of groundwater throughflow which would have otherwise contribute to baseflow discharge in lower catchment areas.

Ruamahanga valley

The Ruamahanga River has entrenched into a relatively narrow valley which runs along the eastern side of the Wairarapa Valley between the eastern hills and the uplifted basement blocks associated with Tiffen Hill and Te Maire ridge. The Q1 and Q2 gravel deposits associated with river entrenchment are typically less than 15 metres deep forming a moderately to highly permeable unconfined (and locally semi-confined) aquifer system which is hydraulically connected to the Ruamahanga River. South of the Huangarua River confluence the thickness of the alluvial sediments increases with individual gravel layers segregating out as wedges of silt-rich aquitard materials thicken down valley into the Lake Wairarapa basin.

Due to the relatively restricted dimensions and high permeability of the Q1/Q2 aquifer system in the Ruamahanga valley, groundwater in this area typically exhibits a high degree of connectivity with surface water.

Lake Wairarapa basin

Lake Wairarapa occupies a large, actively subsiding sub-basin at the southern end of the Wairarapa Valley. In this area reworked alluvial gravel deposits associated with the Tauherenikau and Ruamahanga rivers merge to form a series of discrete confined aquifers which are separated by layers of fine-grained lacustrine and estuarine sediments associated with the lake. These confined aquifers are laterally continuous across a relatively wide area but pinch out before reaching the south coast due to the presence of a basement high across the valley in the vicinity of Lake Onoke. Due to the degree of confinement, confined aquifers in the lower valley exhibit limited direct interaction with surface water, although diffuse leakage from the upper confined aquifer is likely to contribute to the overall water balance of Lake Wairarapa.

Basement ridges

Te Maire ridge and Tiffen Hill (including Fernhill) represent elongate blocks of greywacke basement which have been uplifted along a series of faults which run along the eastern side of the Wairarapa Valley. These structures effectively displace low permeability basement (or older Quaternary gravel in the case of Fernhill) against younger water bearing alluvial sediments in the Parkvale basin and on the lower portion of the Tauherenikau fan. These basement ridges form a groundwater divide between the Ruamahanga River valley and alluvial fan and sub-basin deposits to the west. In the middle valley, Tiffen Hill essentially diverts groundwater flowing through the alluvial fan deposits toward the confluence of the Waiohine and Ruamahanga rivers where a considerable volume of baseflow discharge occurs. Similarly, in the lower valley, Te Maire ridge diverts groundwater flowing through the Tauherenikau fan southwards into the confined aquifer surrounding Lake Wairarapa where it merges with groundwater flowing through the lower section of the Ruamahanga valley.

Splay faults

A series of splay faults (including the Carterton, Masterton and Mokonui faults) associated with the larger Wairarapa Fault cut across the middle and upper sections of the Wairarapa Valley following a NE-SW trend. These recently active faults form a low permeability barrier which impedes groundwater throughflow through the alluvial fan deposits resulting in the discharge of groundwater to the surface via springs and seeps along the respective fault traces. Table B2 provides a summary of hydrogeological units in the Wairarapa Valley including their potential role and contribution to groundwater-surface water interaction.

Table B2: Summary of distribution, physical characteristics and nature of groundwater-surface water interaction in main hydrostratigraphic units in the Wairarapa Valley

Unit	Distribution	Physical characteristics	Nature of surface water/groundwater interaction
Alluvial fans (Q2-Q8)	Alluvial fans extending from the Tararua foothills associated with the Waipoua, Ruamahanga, Waiohine Tauherenikau rivers and Mangatarere Stream	Poorly sorted alluvial gravels in a silt-rich matrix which form moderate to low permeability stratified unconfined to semi-confined aquifers	Alluvial fan aquifers provide a significant contribution to baseflow discharge in lower catchment areas via throughflow into Q1 gravel aquifers. Some local discharge to spring-fed streams in mid to lower fan areas and adjacent to faults. Potential for groundwater abstraction along outer margin of Q1 gravels to result in direct stream depletion effects on main rivers as well as localised effects on spring-fed streams and wetlands. Abstraction from alluvial fan aquifers also has the potential to contribute to cumulative reduction in baseflow discharge at a catchment scale.
Recent alluvial gravels (Q1)	Recent floodplains of the major river systems	Shallow, highly permeable unconfined aquifers exhibiting a high degree of connectivity with surface water	Extensive interaction with main river systems. Significant flow loss to groundwater in upper reaches with discharge back to lower reaches including in some areas extensive spring-fed stream systems. Potential for groundwater abstraction to result in significant stream depletion effects on main stem rivers and spring-fed streams.
Alluvial sub-basins (Q6-Q8)	Te Ore Ore, Parkvale, Carterton, Lake and Onoke sub-basins	Moderately permeable water bearing gravel units interspersed with lower permeability sand silt deposits forming a sequence of semi-confined aquifers	Limited direct interaction with surface water. However, groundwater abstraction from semi-confined aquifers may induce vertical leakage from overlying unconfined aquifers and ultimately contribute to cumulative reduction in baseflow discharge
Ruamahanga valley (Q1-Q2)	Narrow, elongate river valley extending from Opaki to the Lake Wairarapa basin	Shallow moderate to high permeability unconfined aquifer system exhibiting high degree of connectivity with surface water	Extensive interaction with surface water with flow loss/gain occurring according to relative river stage and groundwater levels. Potential for groundwater abstraction to result in direct depletion of river flow
Lake Wairarapa basin	Lower Wairarapa Valley area south of Featherston	Extensive confined aquifer system consisting of water bearing alluvial gravel layers associated with the Ruamahanga River or Tauherenikau fan separated by thick silt aquitards	Limited interaction with surface water.

B.2 Aquifer hydraulic properties

The geological materials forming the main aquifer systems in the Wairarapa Valley exhibit a wide range of hydraulic properties which typically reflect their depositional origin.

Gravel materials (Q2-Q8) forming the alluvial fan deposits associated with the major river systems are characterised as highly heterogeneous reflecting deposition on an actively aggrading alluvial fan surface. These materials tend to be poorly sorted with the relatively high percentage of sand and silt in the gravel matrix restricting aquifer permeability. However, vertical stratification of these materials into layers of higher and lower permeability occurs in some areas forming localised semi-confined aquifers which exhibit low to moderate permeability. In contrast, the alluvial gravel materials underlying the recent floodplains of the major rivers (Q1) have typically been extensively reworked during postglacial river entrenchment resulting in the removal of much of the finer material within the gravel matrix, significantly increasing aquifer permeability.

In the alluvial sub-basins, differentiation between the moderately permeable interglacial gravels and lower permeability silt-dominated glacial deposits is better defined than within the alluvial fan deposits. As a result, the Parkvale, Carterton and Te Ore Ore sub-basins host a series of relatively well-defined semi-confined aquifers which exhibit moderate permeability and a relatively low storage co-efficient.

A large number of aquifer tests have been undertaken in the Wairarapa Valley to support historical resource consent applications. These aquifer tests show a degree of variability between individual test results which is primarily interpreted to reflect the overall heterogeneity of the alluvial gravel materials (although aquifer test methodology and data quality are also likely to contribute to some of the observed variance). The main observation from these tests is the large (up to, and in excess of one order of magnitude) difference in aquifer transmissivity calculated for the Q1 gravel deposits compared to the older, more silt dominated Q2 to Q8 gravels comprising the alluvial fan and sub-basin aquifers.

Gyopari and McAlister (2010a, 2010b and 2010c) undertook an analysis of available aquifer test data and derived the representative aquifer properties outlined in

Table B3. The figures listed are intended to represent the ‘bulk’ hydraulic properties of individual geological units to overcome some of the bias in available aquifer test results which tend to favour bores in areas exhibiting highest aquifer permeability.

Aquifer test results reflect the variability in hydrogeological settings and aquifer hydraulic properties across the various aquifer systems present in the Wairarapa Valley. Many results show evidence of the interception of recharge boundary conditions that may represent induced recharge from local surface waterways (in the case of tests from shallow unconfined aquifers) or vertical leakage from overlying water bearing layers (which may be hydraulically connected to surface water) in the case of tests from deeper semi-confined aquifers. Many aquifer tests also exhibit positive displacement of the recovery curve consistent with an external recharge source.

Table B3: Representative hydraulic characteristics of the main hydrostratigraphic units in the Wairarapa Valley

Geological Unit	Area	Transmissivity (m^2/day)	Hydraulic conductivity (m/day)	Storage[1]
Holocene alluvium (Q1)	Waiohine	4,000 – 6,000	300 – 600	S_y = 5-15%
	Ruamahanga	3,000 – 4,000	300 – 400	S_y = 7-10%
	Mangatarere	1,500 – 2,000	200 – 300	
	Waingawa	2,000 – 3,000	200 – 300	
	Te Ore Ore basin	2,000	200 – 300	S_y = 7-10%
	Huangarua	1,100	100	S_y = 15%
	Turanganui/Tauanui	2,000	200	S_y = 10-15%
Alluvial fan gravels (Q2)	Taratahi/Parkvale	100		
	Tauherenikau	700		S_y = 5-10%
	Waiohine /Mangatarere	100 – 500	10 – 50	S_y = 5-15% $S = 1.5 \times 10^{-4}$
	Waingawa	600	60 – 100	S_y = 5-10%
	Waipoua/Ruamahanga	150	15 – 20	S_y = 3-5%
	Kopuaranga	50	5 – 10	S_y = 3-5%
Alluvial sub-basins (Q2 - Q8)	Parkvale basin	500 – 1,000	50 – 150	$S = 1.5 \times 10^{-4}$
	Te Ore Ore basin	1,000	100	$S = 5 \times 10^{-4}$
	Lake basin	2,750		$S = 1.5 \times 10^{-4}$
	Onoke	320		$S = 1.3 \times 10^{-4}$
Martinborough Terraces	Upper (<60 m deep)	400 – 500		S = 0.0008
	Lower (>60 m deep)	50		S = 0.0002

[1] The storage coefficient (S) is presented as S_y (specific yield) for unconfined aquifers; specific yield is approximately equal to S for unconfined aquifers.

Overall, even given their restricted durations and common issues with data quality, aquifer test results in the Wairarapa valley demonstrate direct effects on surface water in many shallow bores located in relative proximity to surface water. Many deeper tests also demonstrate that vertical leakage induced by pumping has the potential to draw water from overlying unconfined aquifers that may be hydraulically connected to surface water.

B.3 Groundwater levels

B.3.1 Regional groundwater flow pattern

Piezometric surveys undertaken in the Wairarapa Valley show the regional groundwater flow pattern generally follows the local topographic gradient.

In the Upper Valley, groundwater typically flows in a south-easterly direction off the alluvial fan deposits toward the Te Ore Ore plain and the Ruamahanga River upstream of the Waingawa River confluence. The Waingawa and Waipoua rivers exert a strong control on the local groundwater flow pattern which reflects groundwater-surface water interaction along the riparian margin of these rivers. Piezometric contours indicate flow loss from the Waingawa River into the surrounding unconfined aquifer and groundwater discharge to the Waipoua River upstream of the Masterton Fault creating a sub-regional groundwater flow system where flow lost from the Waingawa River contributes to baseflow discharge in the Waipoua River (and springs located along the Masterton Fault trace) via throughflow in the intervening alluvial fan aquifer. This type of relationship is typical of the significant degree of interconnection between groundwater and surface water observed in many areas of the Wairarapa Valley.

In the Middle Valley the regional groundwater flow pattern reflects the regional topographical gradient with groundwater flowing in a southerly direction across the alluvial fan deposits toward the Parkvale and Carterton areas. Towards the eastern side of the valley flows are diverted in a more south-westerly direction due to the presence of the low permeability sediments comprising the Fernhill and Tiffen Hill areas and converge on the Ruamahanga River near the Waiohine confluence. Piezometric contours indicate this section of the Ruamahanga River receives significant baseflow discharge via groundwater throughflow from the Parkvale, Carterton and Greytown aquifer systems. This flow gain from groundwater baseflow discharge is evident in concurrent flow gauging across this reach of the Ruamahanga River as further described in Appendix B.4.1.

In the Lower Valley groundwater flow on the Tauherenikau fan occurs in a south-easterly direction sub-parallel to the river before being diverted in a more southerly direction around Te Maire ridge into the Lake Wairarapa basin. In the lower Ruamahanga valley groundwater flow generally parallels the river channel along a southerly alignment before swinging to a more south-westerly direction as it merges with flow from the Martinborough Terraces and enters the Lake Wairarapa basin.

Figure B2 shows a plot of piezometric contours across the Wairarapa Valley derived from groundwater level measurements undertaken in March 2007.

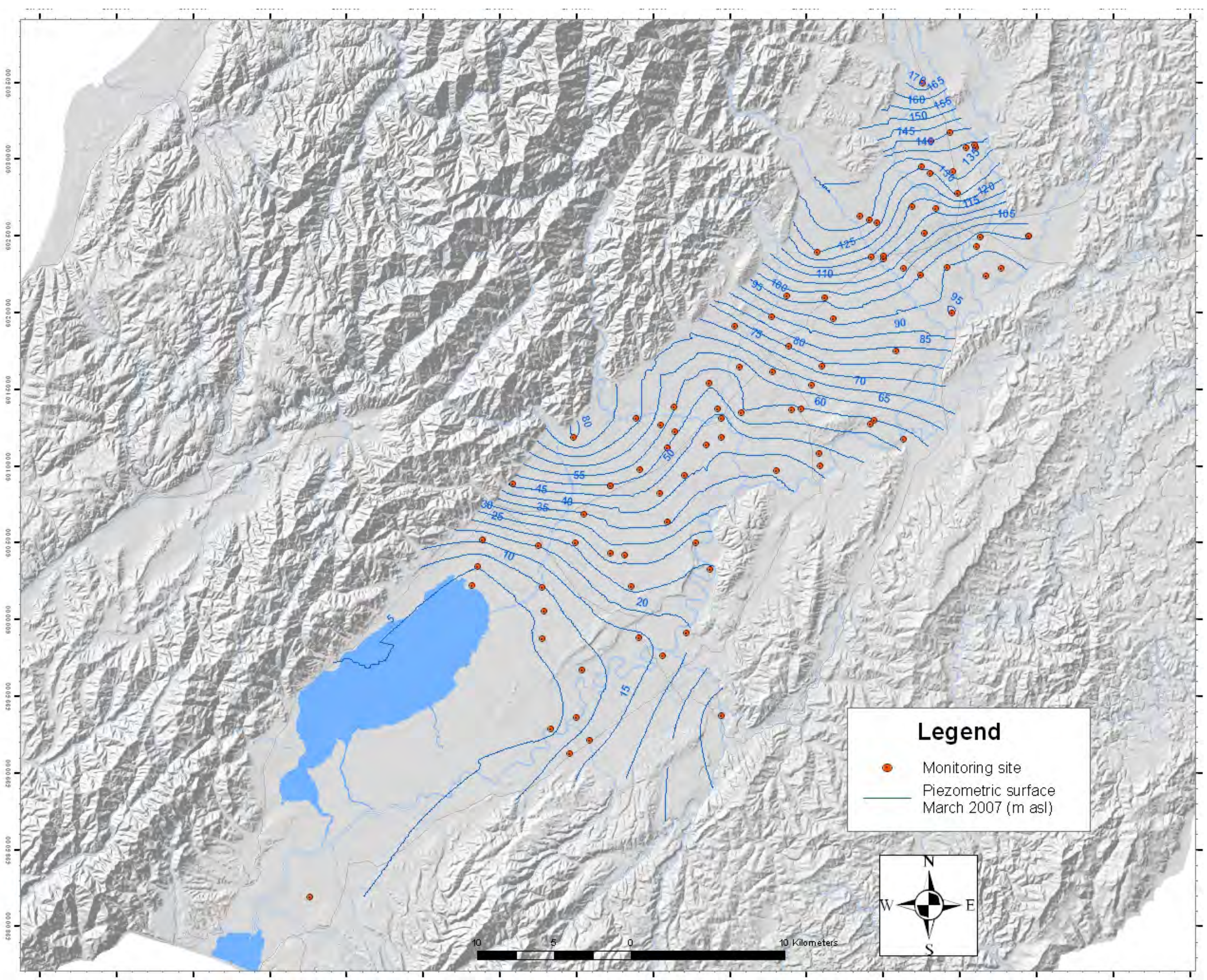


Figure B2: Piezometric contours in the Wairarapa Valley, March 2007

B.3.2 Temporal groundwater level variations

Greater Wellington maintains a network of manual and automatic groundwater level recording sites located in the main aquifer systems across the Wairarapa Valley. The temporal variation in groundwater levels at these sites typically reflects the nature of the hydraulic connection between the aquifer system and adjacent surface waterbodies.

Along the riparian margins of the main river systems groundwater levels typically exhibit a close relationship with variations in river stage. Figure B3 shows a plot of groundwater levels recorded in the shallow unconfined Q1 aquifer in the Greytown area in bore S26/0490, located approximately 1.5 kilometres from the Waiohine River. The figure shows groundwater levels respond rapidly to changes in river stage, typically peaking within 1 to 2 days after the peak river discharge.

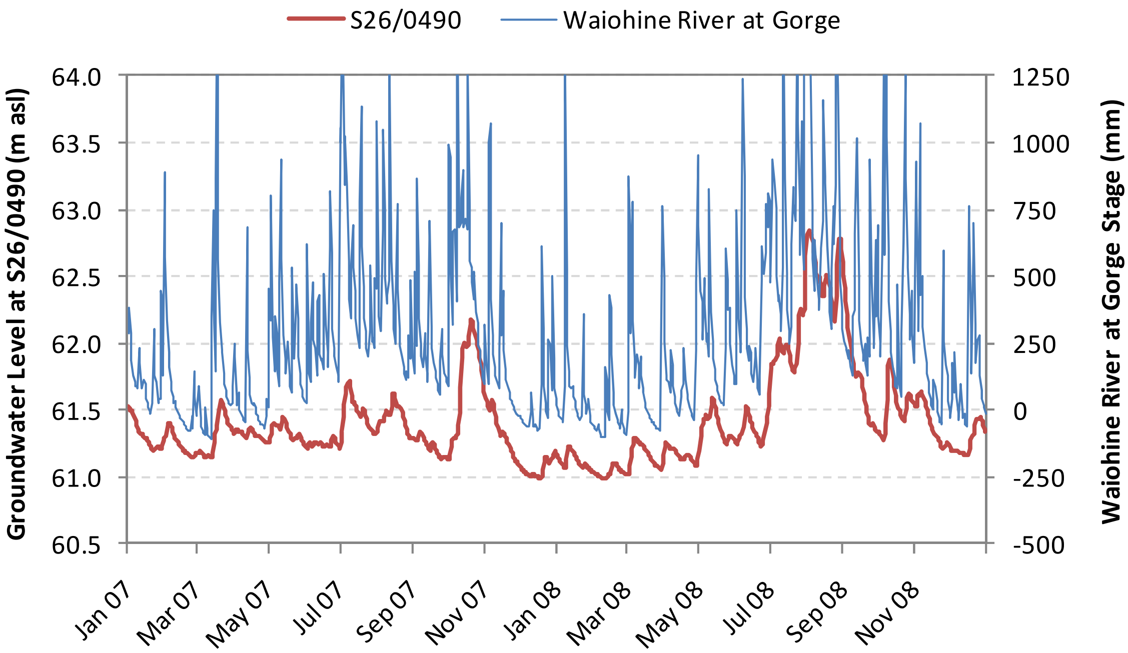


Figure B3: Temporal variations in groundwater levels in a shallow bore in the Greytown area (S26/0490) and Waiohine River stage, 2007-08

A similar temporal groundwater level response to river stage variations is observed along the margins of the Ruamahanga, Waipoua, Waingawa, Waiohine and Tauherenikau rivers reflecting significant interaction between the river and adjacent Q1 aquifers. In these areas groundwater level response to river stage variations typically becomes increasingly dampened with depth and distance from the river channel. However, in both the Greytown area and the lower Ruamahanga valley a clear relationship is observed between groundwater levels and river stage variations up to 4 kilometres from the river channel.

The amplitude of the observed variations in groundwater levels of up to one metre in response to individual high river stage events indicates significant transient flux between the river and aquifers. However, although groundwater levels in these aquifers exhibit considerable short-term variations in response to river stage, limited change in storage is observed on an inter-annual basis reflecting the relatively constant recharge contribution from the major rivers.

In contrast, groundwater levels in shallow unconfined aquifers on the alluvial fans away from the major river systems show little, if any, relationship with river stage. For example, groundwater levels in the unconfined aquifer in the Parkvale area (bore S26/0738) show little or no relationship with river flow, instead tracking seasonal variations in rainfall recharge (Figure B4).

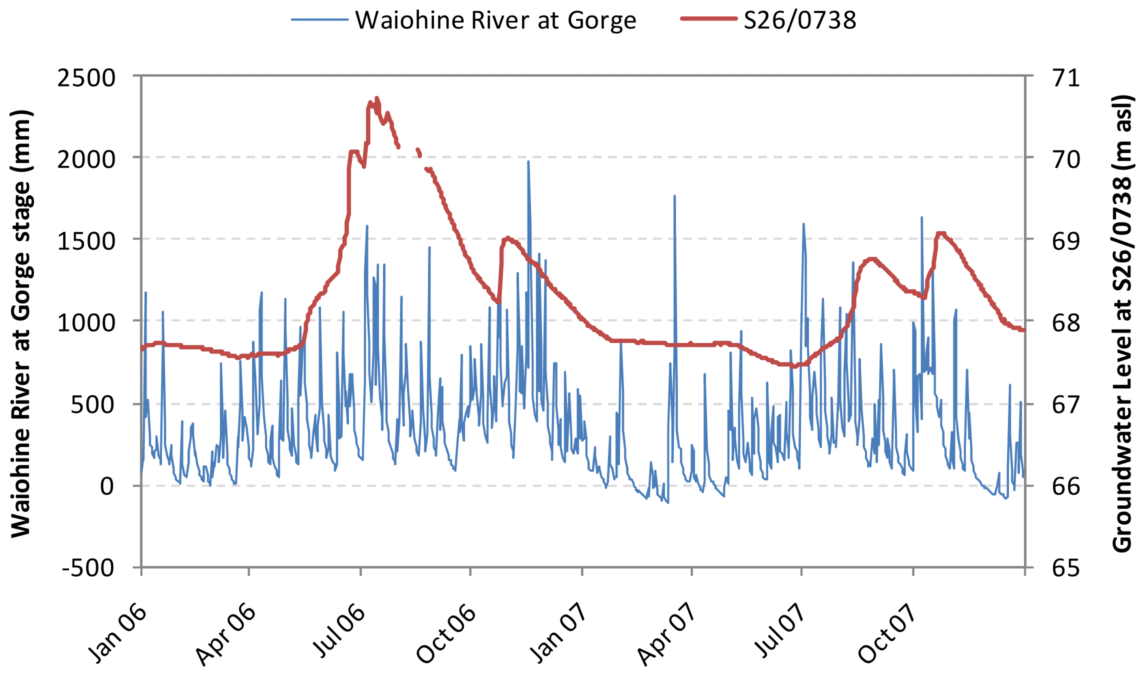


Figure B4: Temporal variations in groundwater levels in the unconfined aquifer in the Parkvale area (bore S26/0738) and stage height in the Waiohine River, 2006-07

Similarly, groundwater levels recorded in deeper, semi-confined aquifers typically show a distinct pattern of temporal variation which is influenced by seasonal recharge as well as the volume of groundwater abstraction. For example, Figure B5 shows groundwater levels recorded in semi-confined aquifers in the Te Ore Ore (bore T26/0494) and Parkvale (bore S26/0743) alluvial sub-basins over the period 2006 to 2008 inclusive. The plots show temporal groundwater level variations in these aquifer systems are dominated by drawdown resulting from abstraction during the summer months followed by a gradual water level recovery during the subsequent winter. This recovery is principally due to vertical leakage from overlying water bearing strata. This vertical leakage into deeper aquifers may contribute an overall reduction in groundwater baseflow discharge to surface water at a catchment scale.

More detailed analysis of spatial and temporal variations in groundwater level are provided in Gyopari and McAlister (2010a, 2010b and 2010c).

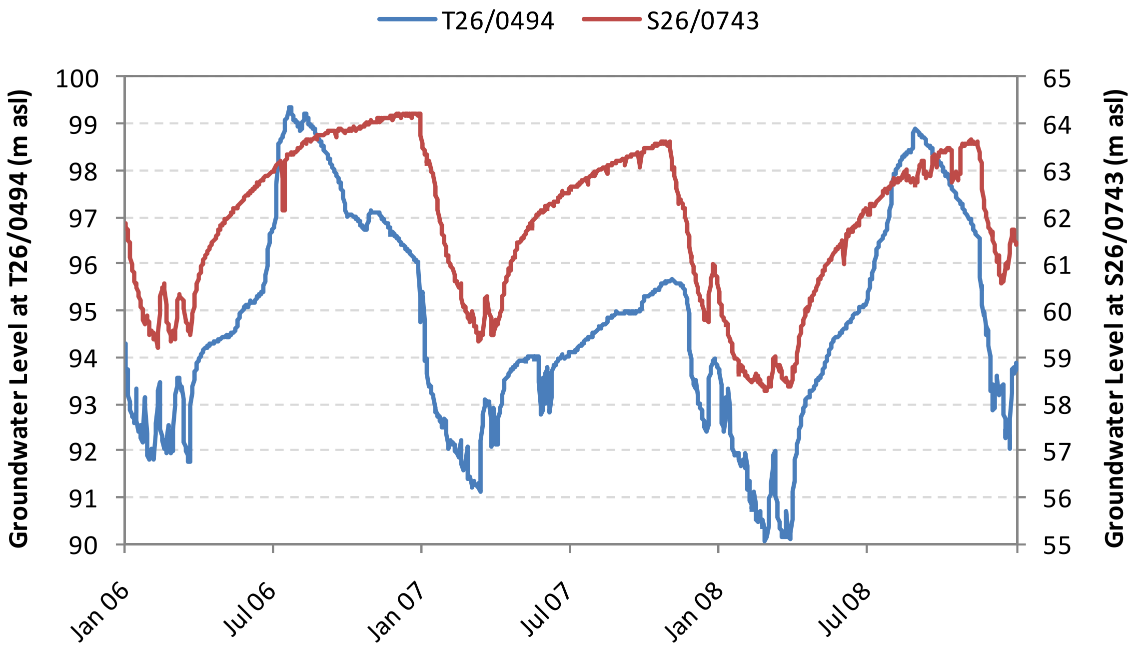


Figure B5: Groundwater levels in semi-confined aquifers in the Te Ore Ore (bore T26/0494) and Parkvale (bore S26/0743) alluvial sub-basins, 2006-08

B.4 Surface water discharge

Natural interaction between groundwater and surface water is evident across much of the Wairarapa Valley. The nature and extent of this interaction is evident in the spatial variation of flow gain and loss observed in the major river systems as well as the extensive network of springs, spring-fed stream and wetlands which occur in many areas. Many of these spring systems and wetland areas form unique and highly valued aquatic environments that are remnants of the more extensive systems which occurred prior to large-scale agricultural development.

The following section provides an outline of surface water monitoring data that illustrate the extent and nature of natural groundwater-surface water interaction in the Wairarapa Valley.

B.4.1 Observed flow gain/loss in the major river systems

Concurrent flow gauging undertaken in the major river systems indicate a complex pattern of flow gain and loss reflecting extensive interaction between the main river channels and the shallow, unconfined high permeability aquifers hosted in the Q1 gravels deposited along the channel margins.

Figure B6 shows the results of a series of concurrent gauging runs undertaken in the Waiohine River during low flow conditions in 1981, 2006 and 2007. The gauging data (adjusted to account for surface water inflows and major abstractions) indicate a consistent flow loss of between 450 and 1,300 L/s between the railway bridge and the SH2 bridge, a distance of approximately 8 kilometres and a slight increase (due to groundwater discharge) of between 100 to 200 L/s in the reach below SH2. This pattern of upstream flow loss and downstream flow gain is interpreted to reflect the seepage flux from the Waiohine River to the Q1 gravels above SH2 and return flow to the river via baseflow discharge below this point.

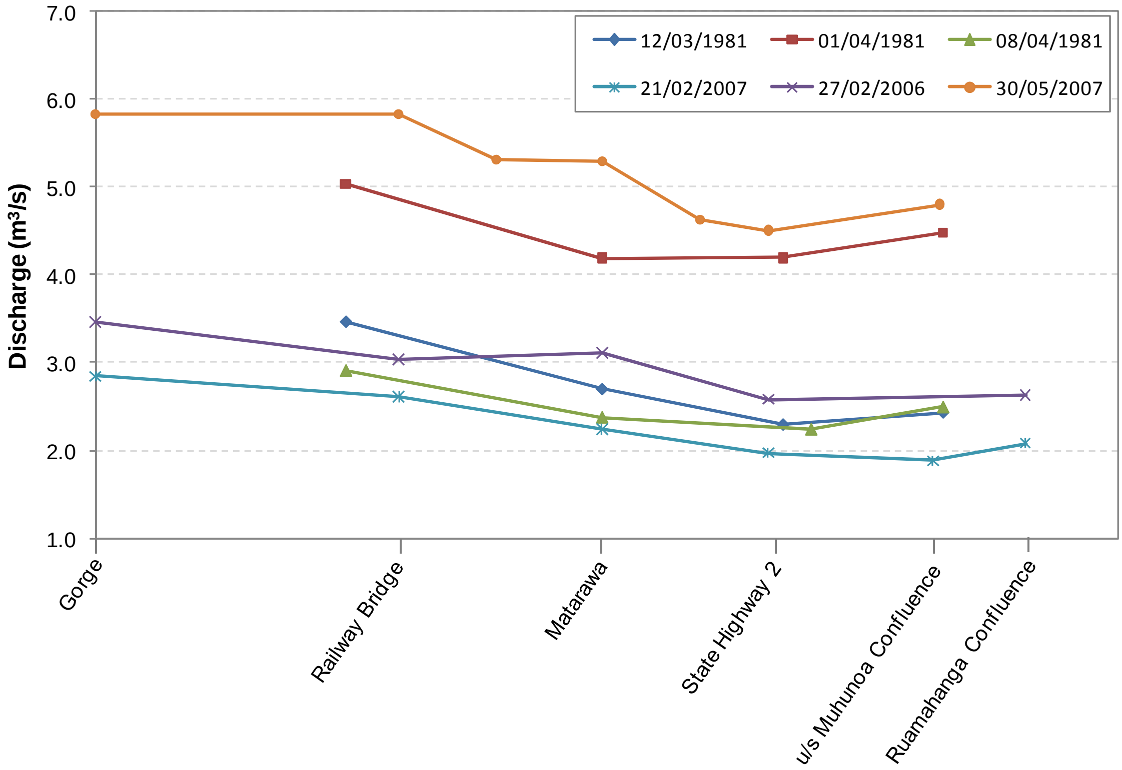


Figure B6: Results of concurrent gauging runs in the Waiohine River. Note that the major tributary inflows (such as the Mangatarere and Muhunoa Streams) have been subtracted from the gauging results.

Figure B7 shows the observed correlation between flows recorded at the Waiohine River at Gorge monitoring site and a temporary flow recorder installed at the SH2 bridge during 2008. These data show an excellent correlation (R^2=0.95) for flows less than 10 m^3/s (generally stable baseflow conditions) at the SH2 bridge site with increasing scatter during higher flows. The observed correlation indicates a relatively constant flow loss of between 1.6 to 1.7 m^3/s to the riparian aquifer during low flow conditions. Based on this estimated flow loss, the likely seepage flux from the Waiohine River to the riparian Q1 aquifer system in the Greytown area is likely to be in the order of 140,000 m^3/day.

Concurrent gaugings undertaken in the other major rivers emerging from the Tararua Range into the Wairarapa Valley show a similar pattern of flow loss in their upper reaches where they emerge from the Tararua foothills and flow gain in lower reaches. This upstream flow loss is interpreted to represent recharge to the highly permeable riparian Q1 gravel aquifers, with groundwater discharge occurring in lower reaches via direct seepage into the river channel or discharge in spring-fed streams (such as the Masterton and Greytown springs and Stonestead Creek). This interaction between river discharge and throughflow in riparian Q1 aquifers is particularly evident in the Mangatarere Stream which commonly goes dry through its middle reaches during the summer.

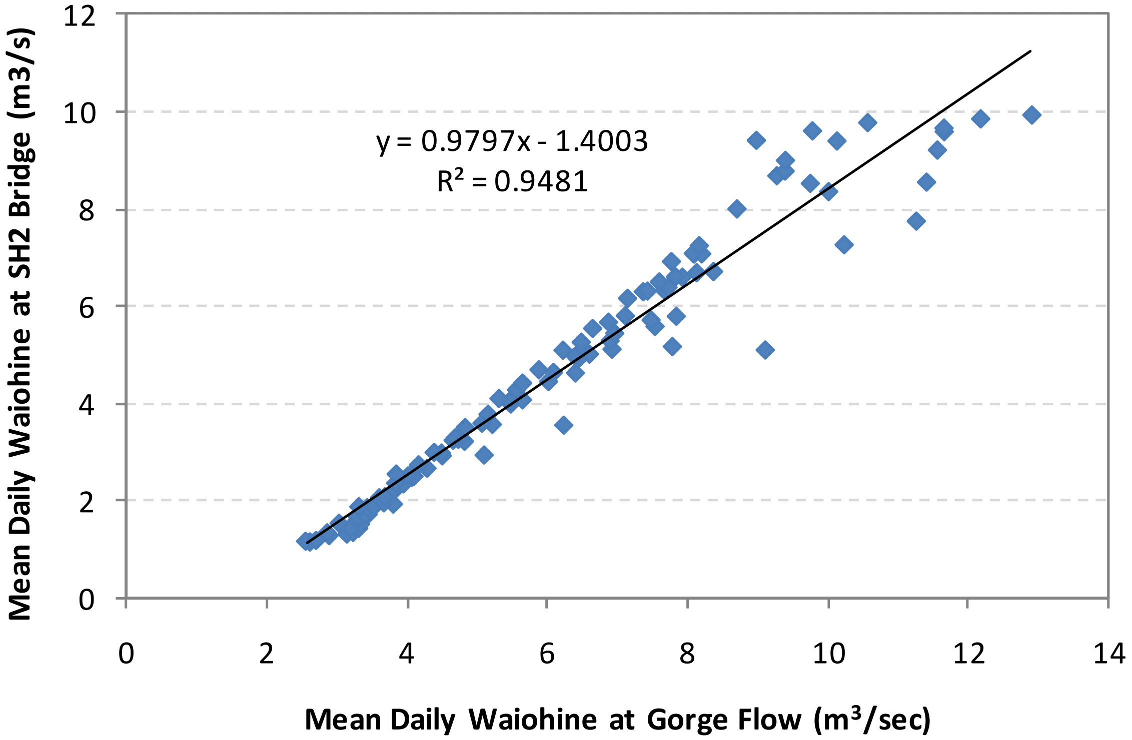


Figure B7: Correlation between mean daily discharge in the Waiohine River at the Gorge and SH2 monitoring sites

Groundwater throughflow in the Q1 aquifers may also contribute recharge to the outer margins of the surrounding alluvial fans aquifers, particularly in upper fan areas. For example, flow loss from the Waingawa River makes a significant contribution to throughflow in the alluvial fan gravels on the true left bank which in turn contributes to surface water discharge in the lower reaches of the Waipoua River and springs emerging along the Masterton Fault.

The Ruamahanga River shows a slightly different spatial variation in flow gain and loss compared to the other river systems. In the upper catchment, gauging results indicate a relatively small flow gain (~300 to 400 L/s) upstream of the Mokonui Fault during low flow conditions. However, downstream of the fault, a consistent flow loss of approximately 1 m^3/s is observed indicating significant discharge from the river to the adjacent riparian aquifer. This pattern of gain and loss is inferred to reflect the influence of vertical displacement on the Mokonui Fault which increases the thickness of valley-fill alluvium to the east of the fault creating conditions conducive to recharge from the river (Gyopari and McAlister 2010a).

An overall flow increase of approximately 1,200 L/s is observed in the Ruamahanga River between the Mokonui Fault and the Waingawa River confluence reflecting the return of the upstream flow loss combined with additional discharge of groundwater throughflow from the surrounding riparian aquifer. Between the Waingawa confluence and the Gladstone Bridge gauging results indicate the river does not gain or lose appreciable quantities of water. This may reflect the relatively restricted lateral extent of the Ruamahanga valley across this reach with local movement of water into and out of the river depending on the relative hydraulic gradient between the river and surrounding riparian aquifer. Between the Gladstone Bridge and the Waiohine River confluence appreciable (>1 m^3/s) flow gain is observed reflecting the baseflow contribution of throughflow from aquifers in the Middle Valley catchment which drain around the southern margin of Tiffen Hill toward the confluence of the Waiohine and Ruamahanga rivers.

In the lower Ruamahanga River flow loss is observed between Morrisons Bush and Walls. This loss is interpreted to reflect a combination of seepage losses into the deeper confined aquifer system in the Lake Wairarapa basin as well as throughflow of water into Lake Wairarapa via recent gravel-filled paleochannels. Gauging results indicate a consistent flow gain between Walls and Pukio which is interpreted to reflect baseflow discharge from groundwater throughflow in the Martinborough Terraces and the shallow unconfined aquifer along the riparian margin of the Dry River.

Figure B8 shows a map of interpreted flow gains and losses in the major river systems across the Wairarapa Valley.

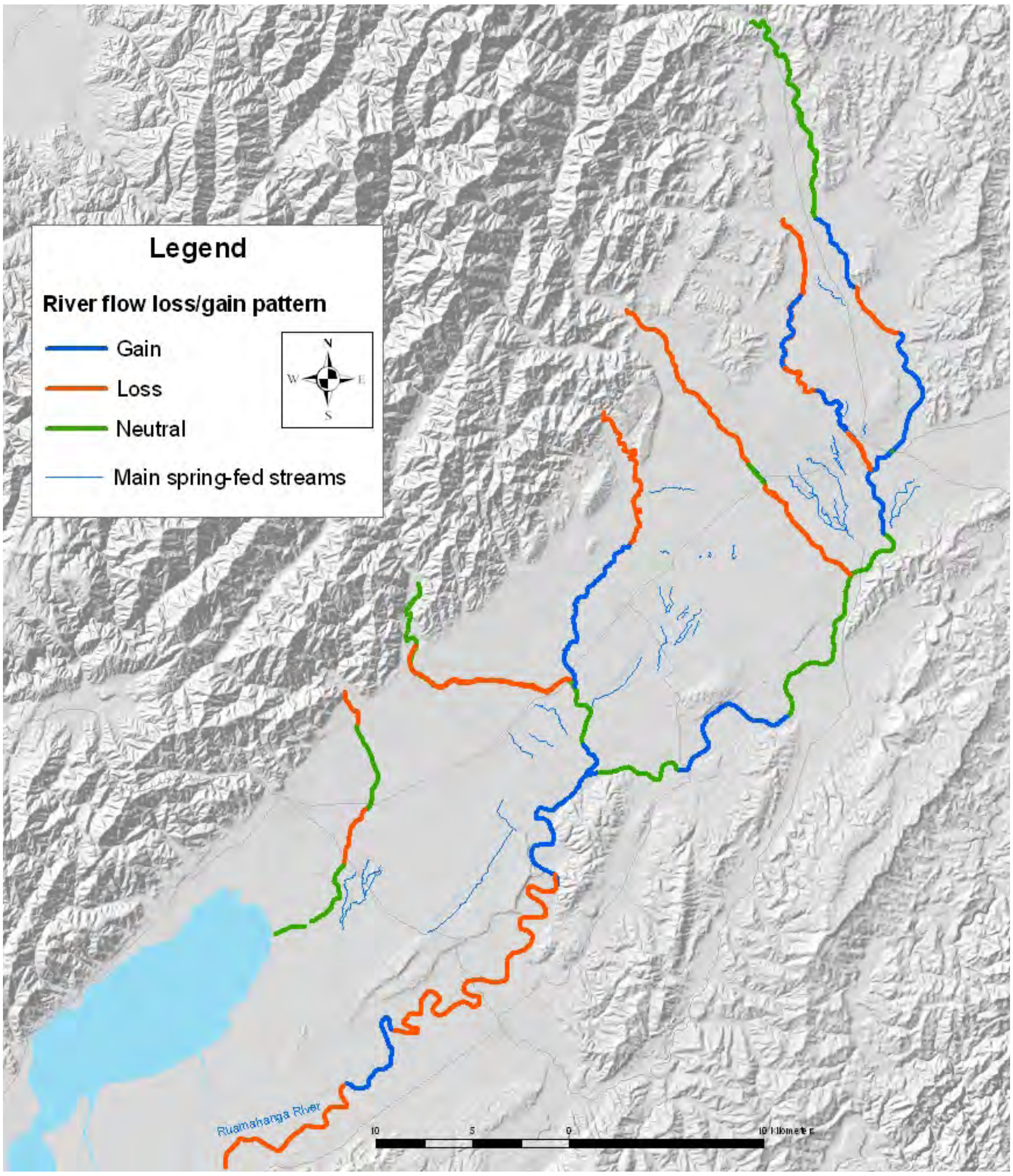


Figure B8: Observed flow gains and losses in the major river systems in the Wairarapa Valley. Note this map depicts flow gain or loss to groundwater, and not the effects of tributary inflows or major abstractions.

B.4.2 Springs and wetlands

The occurrence of springs and wetlands commonly reflects local interaction between shallow groundwater and the surface environment. These features (commonly referred to as *groundwater dependent ecosystems*) form unique environments which support high terrestrial and aquatic biodiversity values. Due to their dependence on shallow groundwater these systems are typically highly susceptible to environmental change resulting from alterations to the natural hydrological cycle associated with drainage development and groundwater abstraction.

<u>Upper Valley</u>

In the Upper Valley the Masterton Springs comprise an extensive channel network occupying the area between the Masterton Fault, Ruamahanga River and the Waingawa River. Many of these springs emerge along the trace of the Masterton Fault which appears to impede flow of groundwater through the Waingawa River alluvial fan forcing it to the surface. The main stems in this spring system include the Makoura and Kuripuni streams which carry a cumulative discharge estimated at between 150 to 200 L/s during summer low flows.

The Poterau Stream is a spring-fed stream which traverses the Te Ore Ore plains. This stream flows along the geological boundary between the silt-rich alluvium sourced from the Whangaehu catchment and the more gravel rich alluvium associated with the Ruamahanga River. Summer discharge in this system is estimated to be less than 20 L/s with a noticeable reduction in summer low flows in recent years attributed to increased groundwater abstraction in the local area (Gyopari and McAlister 2010a).

Waipipi Stream originates north of the Waipipi Fault and discharges to the Ruamahanga River near the Masterton Fault. Gauging data indicate a summer discharge of 20 to 30 L/s, primarily sourced from inflows above the Waipipi Fault. The Golf Course spring emanates on the alluvial fan north of Lansdowne Hill and flows southward joining the Waipoua River near Masterton. Summer low flow in this stream is estimated to be in the range of 20 to 50 L/s.

Significant wetlands in the upper Wairarapa Valley are restricted to areas along the riparian margin of the Ruamahanga River upstream of the Waipoua River confluence.

<u>Middle Valley</u>

The largest spring system in the Wairarapa Valley comprises Papawai Stream, Tilsons Creek and Muhunoa Stream which are collectively referred to in this report as the Greytown Springs. These streams drain the shallow alluvial aquifer underlying the Waiohine floodplain near Greytown and have a combined mean discharge of approximately 1,500 L/s. The estimated mean annual low flows for these streams range from 550 L/s in Muhunoa Stream, 200 L/s in Papawai Stream and 140 L/s in Tilsons Creek (Keenan 2009).

Spring discharges occur along both the Masterton and Carterton faults where the fault structure results in several metres of topographical displacement and appears to impede the lateral movement of groundwater through the underlying alluvial sediments. Along the Masterton Fault discharge occurs via three main springs (the Waingawa Spring, Parkers Stream and Wiltons Drain) which carry a mean discharge of approximately

120 L/s reducing to less than 30 L/s during summer. Considerably more groundwater discharges from several major springs along the Carterton Fault. These springs are interlinked with the Taratahi Water Race system making it difficult to quantify the overall magnitude of groundwater discharge. Butcher (2007) estimated a mean flow approximately 230 L/s from springs along the Carterton Fault.

Groundwater discharges to a series of stream channels (collectively known as the Parkvale Springs) which traverse the Parkvale area. Again these springs merge with the Taratahi Water Race system making it difficult to quantify the overall magnitude of groundwater discharge. Butcher (2007b) estimated a mean discharge of approximately 150 L/s from this spring system.

A number of small groundwater-fed streams emerge on the lower slopes of the Waiohine-Mangatarere fan west of Carterton including Beef Creek, Enaki and Kaipaitangata streams. Discharge in Beef Creek has been gauged at approximately 60 L/s in summer, increasing to 1,880 L/s in winter.

Significant wetland areas in the middle valley include the Waingawa Swamp and Allens/Lowes Bush which are associated with topographic variations and linked to groundwater discharge along the Masterton and Carterton faults respectively. Riparian also wetlands occur along the outer margin of the Ruamahanga River floodplain including Carters Bush and Taumata Lagoon near the confluence of the Waiohine and Ruamahanga rivers.

Lower Valley

Two main spring systems occur in the lower Wairarapa Valley: the Otukura Stream and Stonestead (Dock) Creek, in addition to numerous wetland areas in the vicinity of Lake Wairarapa and Lake Onoke.

Otukura Stream drains a catchment on the lower section of the Tauherenikau alluvial fan along the eastern margin of Te Maire ridge. This stream forms part of the Battersea Drainage Scheme which comprises an artificial or highly modified channel system constructed during the 1950s to drain this section of the valley. Monitoring by GWRC indicates a mean discharge of 525 L/s and a 1-day mean annual low flow (MALF) of 76 L/s. Figure B9 shows discharge recorded in the Otukura Stream during 2008. The plot clearly shows the stable baseflow during summer and autumn followed by seasonal rise in discharge during winter and spring when groundwater levels are higher and there is a greater contribution from surface runoff.

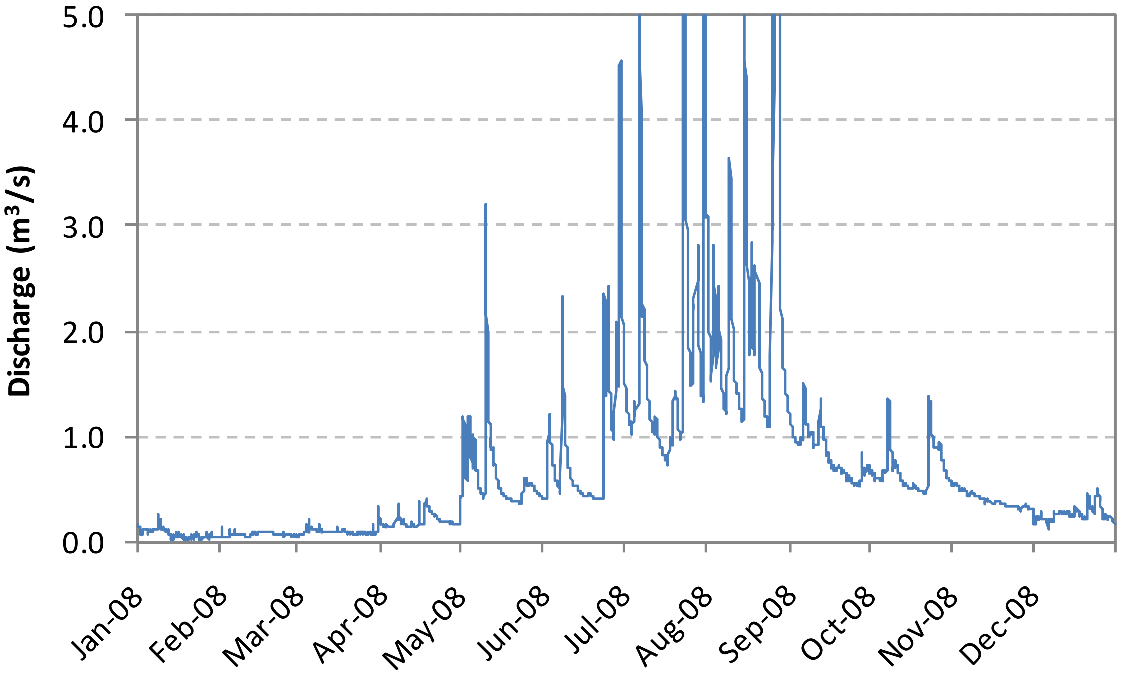


Figure B9: Discharge recorded in Otukura Stream (at Weir) during 2008

Stonestead Creek comprises two main channels which run parallel to the Tauherenikau River across the middle section of the Tauherenikau alluvial fan. Stonestead Creek carries a low flow of approximately 500 L/s, principally derived from spring inflows in the vicinity of SH53 where the stream intercepts throughflow from the Tauherenikau River. Interestingly, the MALF for cumulative discharge in Stonestead Creek is higher than that in the lower reaches of the Tauherenikau River reflecting the significant degree of interaction between the surface water systems which occurs via groundwater throughflow.

The primary wetland areas in the Lower Valley occur around the margins of Lake Wairarapa and Lake Onoke. These wetland areas are remnants of the extensive wetland areas which extended across much of the area prior to agricultural development. Some small relatively isolated wetland areas also occur on the outer margin of the Ruamahanga River floodplain.

Figure B10 identifies the general location of the major spring-fed streams systems and wetland areas across the Wairarapa Valley. More detailed information on stream locations and discharge characteristics are outlined in Gyopari and McAlister (2010a, b and c) and Wilson (2008) with detailed assessment of the hydrology of selected streams outlined in specific Greater Wellington technical publications including Butcher (2007a), Butcher (2007b), Watts (2007) and Watts (2009).

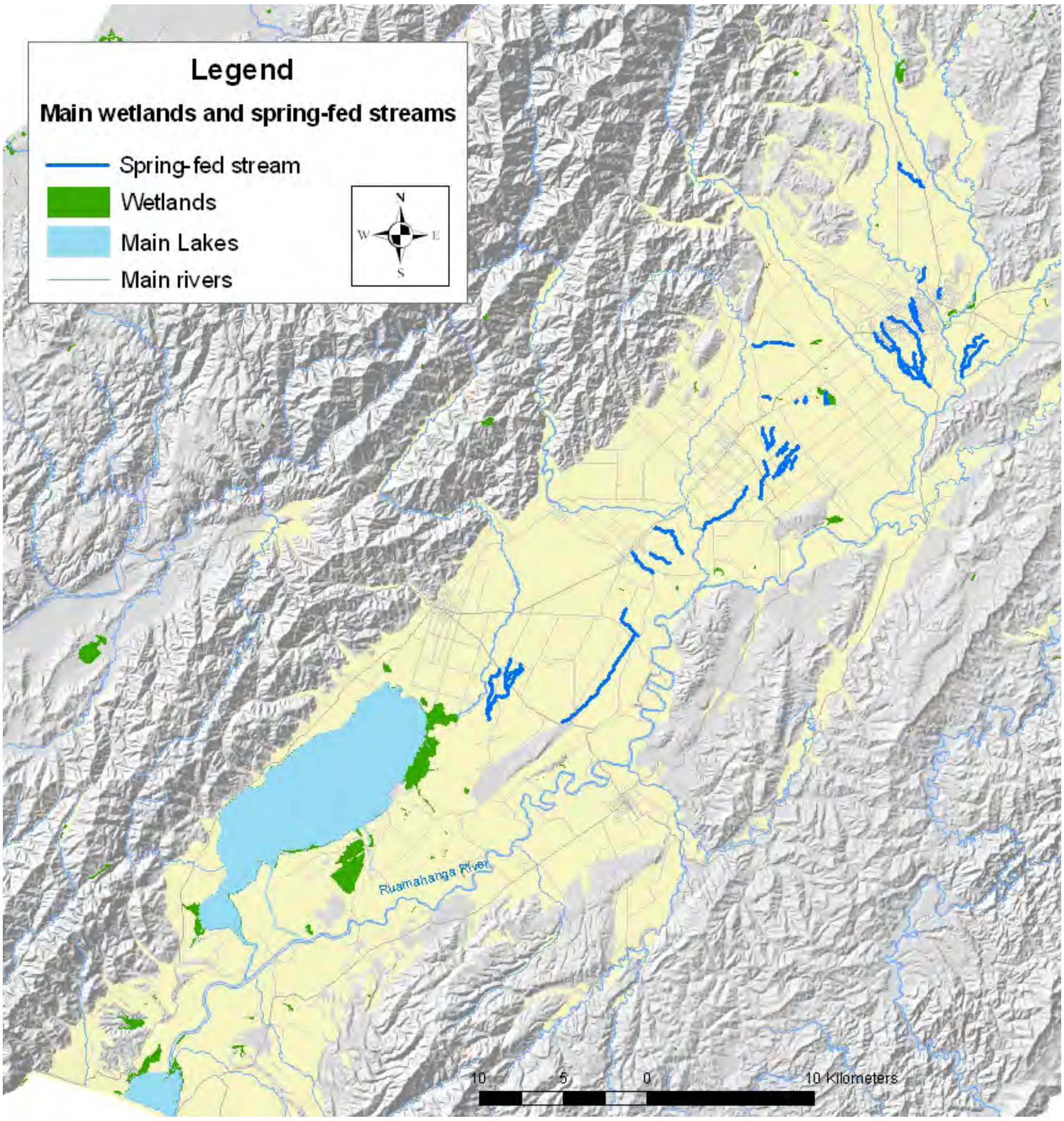


Figure B10: Main spring-fed stream and wetland environments in the Wairarapa Valley

B.5 Groundwater quality

Due to differences in the natural chemical composition of groundwater and surface water resulting from naturally occurring geochemical processes and impacts of land use activities, groundwater quality analyses often provide useful information to characterise recharge sources and the extent of groundwater-surface water interaction.

Daughney (2007) undertook analysis of groundwater and surface water quality data collected across the Wairarapa Valley using two multivariate statistical methods (hierarchical cluster analysis (HCA) and discriminant analysis (DA)) combined with estimated of groundwater residence time derived from analysis of environmental tracers (tritium, CFC and SF6).

Results of the HCA identified two major hydrochemical categories:

- Category A - groundwater containing relatively low dissolved ion concentrations with calcium (Ca) and bicarbonate (HCO_3) as the dominant cation and anion respectively. This type of chemistry was expected in young groundwater containing a significant river recharge component;

- Category B - groundwater containing higher concentration of dissolved ions with sodium (Na) and bicarbonate (HCO_3) as the dominant cation and anion respectively. This type of chemistry was interpreted to represent groundwater which is older than Category A water and/or which contains a higher proportion of recharge from rainfall infiltration (salts are accumulated during infiltration through the soil zone).

Analysis of available water quality data clearly differentiated the young, river recharged groundwater within the shallow unconfined aquifers underlying the recent Q1 gravels along the riparian margins of the major river systems from rainfall-derived groundwater within the surrounding alluvial fan deposits. In turn, recent rainfall recharged groundwater at shallow depths in the alluvial fan deposits was differentiated from the older, geochemically evolved (and frequently reduced) groundwater in deeper semi-confined and confined aquifers in the alluvial basins. Figure B11 shows the HCA results of groundwater samples from the Middle Valley area.

Overall, water chemistry data reflect the high degree of interaction between surface water and groundwater within the riparian Q1 aquifers. However, groundwater along the outer margins of the Q1 aquifers commonly exhibits intermediate composition which is likely to reflect flow exchange between the Q1 and alluvial fan aquifers in many areas.

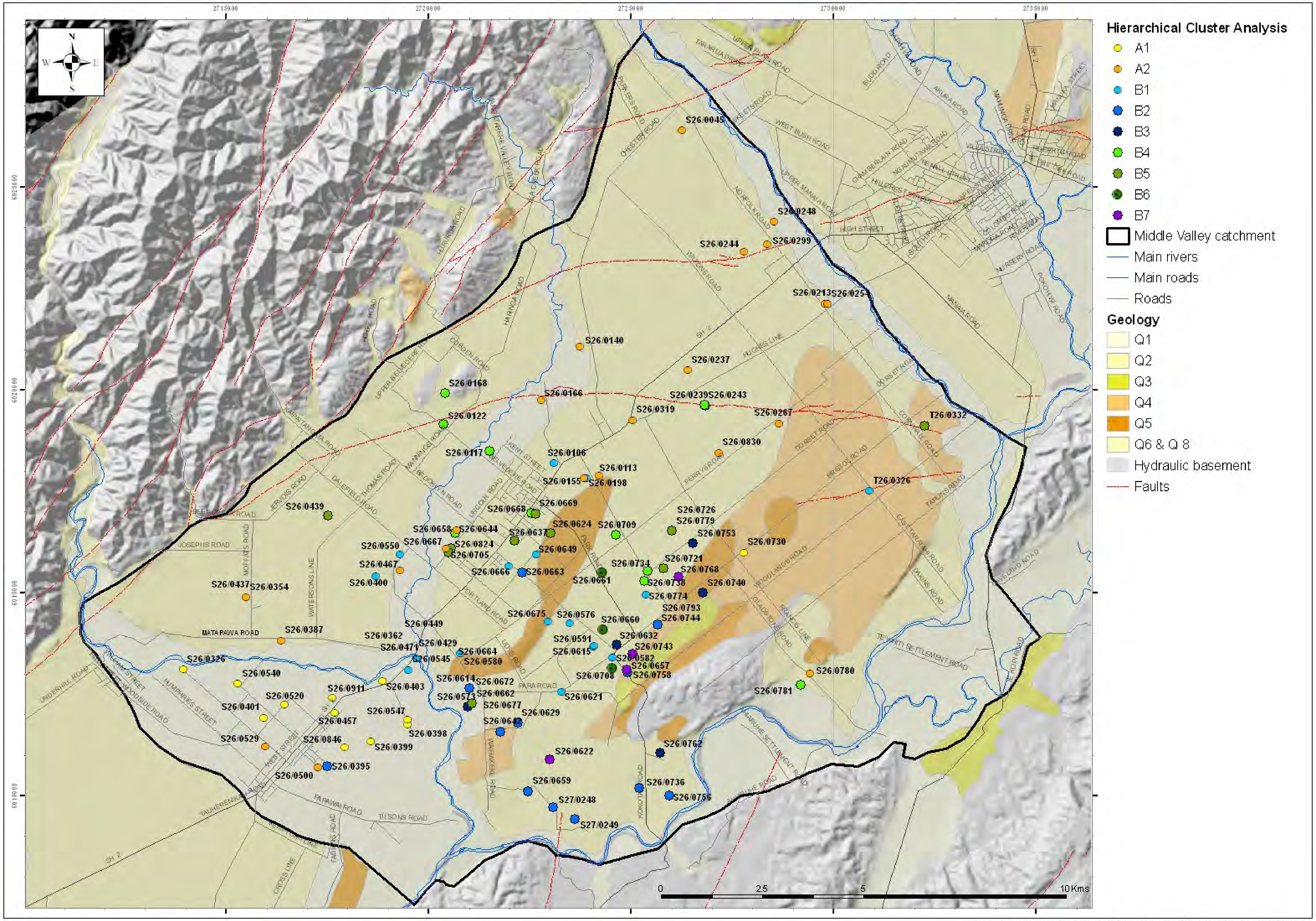


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Figure B11: Groundwater HCA results in the Wairarapa Middle Valley (Gyopari and McAlister 2010b)

B.6 Conceptual model of groundwater-surface water interaction

Information outlined in the preceding sections has identified that significant components of the groundwater balance for aquifers in the Wairarapa Valley are associated with fluxes between shallow groundwater and surface water.

Gauging results and groundwater level hydrographs indicate significant recharge from the major rivers into surrounding riparian aquifers which typically comprise relatively thin sequences of highly permeable Q1 alluvium. This recharge generally occurs on the upper section of the large alluvial fan deposits surrounding the major river systems. On the distal alluvial fan areas natural groundwater discharge occurs as river baseflow, spring flow and diffuse seepage to wetlands and lakes. Groundwater circulation through deeper, semi-confined aquifers, principally recharged by rainfall infiltration across the alluvial fans, also contributes to groundwater baseflow discharge in lower catchment areas.

The major fault systems which cross the Wairarapa Valley also appear to influence the nature of groundwater-surface water interaction. On the alluvial fan deposits these structures impede groundwater throughflow causing groundwater to emerge as springs and seeps along the respective fault traces.

Figure B12 presents a simple conceptual model illustrating the general nature of groundwater-surface water interaction across the Wairarapa Valley in both section and plan view. The hydrogeological setting depicted shows the significant interaction between groundwater and surface water within the shallow, unconfined alluvial aquifers along the riparian margins of the major rivers. This interaction typically involves flow loss from the major rivers to riparian Q1 aquifers across the upper section of the alluvial fan deposits, with return flow via baseflow and spring-fed stream discharge supplemented by throughflow from Q2 to Q8 aquifers hosted in the surrounding alluvial fan deposits. Across the mid-fan areas rivers may gain or lose flow depending on the relative hydraulic gradient between river stage and surrounding groundwater levels. Flow exchange between the Q1 aquifers and surrounding alluvial fan gravels may also occur in some areas (e.g. the Waingawa catchment)

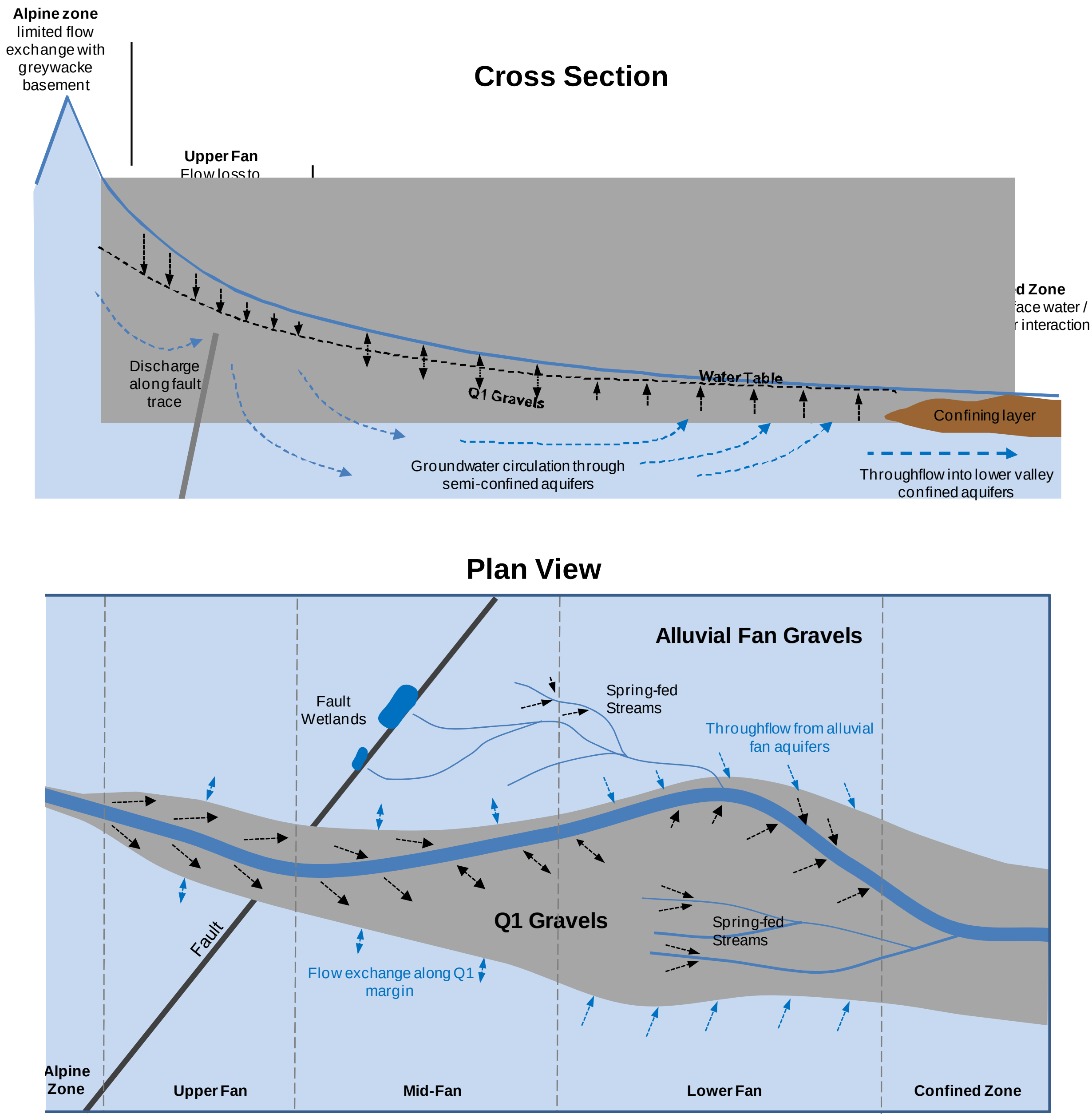

Figure B12: Conceptual model of groundwater-surface water interaction in the Wairarapa Valley

Appendix C

Appendix C: Quantifying groundwater abstraction effects on stream flow

C.1 Introduction

Gyopari and McAlister (2010a, 2010b and 2010c) documented the development of three separate numerical groundwater flow models for the Upper, Middle and Lower subcatchments of the Wairarapa Valley which were developed during Phase 2 of the Wairarapa Valley groundwater resource investigation. These numerical models are utilised in this section as the basis for application of the framework for conjunctive management of groundwater and surface water allocation in the Wairarapa Valley proposed in Sections 3 and 4 of the main report.

In order to develop and refine the proposed framework for conjunctive management in the Wairarapa Valley, outputs from the models have been used in two ways:

- **Global pumping scenarios** are utilised to characterise the groundwater baseflow contribution to surface water and identify the potential magnitude and nature of stream depletion effects resulting from groundwater abstraction from various water bearing units based on modelling of existing groundwater abstraction; and,

- **Individual pumping scenarios** are utilised to characterise the potential nature of direct stream depletion effects resulting from groundwater abstraction from varying distances and depths around individual surface water bodies.

This section presents an overview of scenario testing undertaken during the development of this report. More extensive details of scenario results are provided in Appendix D to F which detail groundwater allocations developed for individual water management zones and the geometry and extent of the proposed Category A and Category B areas in each water management zone.

C.2 Groundwater baseflow contribution

To illustrate the contribution of groundwater discharge to stream baseflow in the Wairarapa Valley, Figure C1 shows a plot of the calculated flux from surface water into and out of the Middle Valley model over the period 1992 to 2006. These fluxes represent the total river recharge and baseflow discharge (including spring flow and baseflow discharge to the main rivers) calculated to occur across the Middle Valley Model domain.

The blue curve on the graph represents calculated river recharge (i.e. seepage flux). The graph shows river recharge is relatively uniform varying from around 100,000 m^3/day (1.2 m^3/s) during summer low flows to approximately 200,000 m^3/day (2.3 m^3/s) during winter. The temporal variation in this recharge is largely driven by the seasonality of rainfall recharge which increases groundwater levels (with a consequent reduction in river recharge) during the winter months. The inverse relationship between baseflow discharge and river recharge reflects the contribution of groundwater storage to baseflow discharge, particularly during periods of high groundwater levels (typically during winter/spring).

In contrast, the red curve shows modelled groundwater discharge to surface water (i.e. baseflow) follows an annual cycle, typically peaking in late winter (July/August) and gradually declining during spring and summer to reach a minimum in early autumn (April/May). The magnitude of the calculated baseflow discharge varies from up to 800,000 m^3/day (9.3 m^3/s) during winter to around 200,000 m^3/day (2.3 m^3/s) in late summer. Given the estimated 1-day MALF for the Ruamahanga River at Morrisons Bush is 10.7 m^3/s (Cawthron 2008), it is clear that baseflow discharge from the Middle Valley model domain makes a major contribution to river flow during low flows in this section of the catchment.

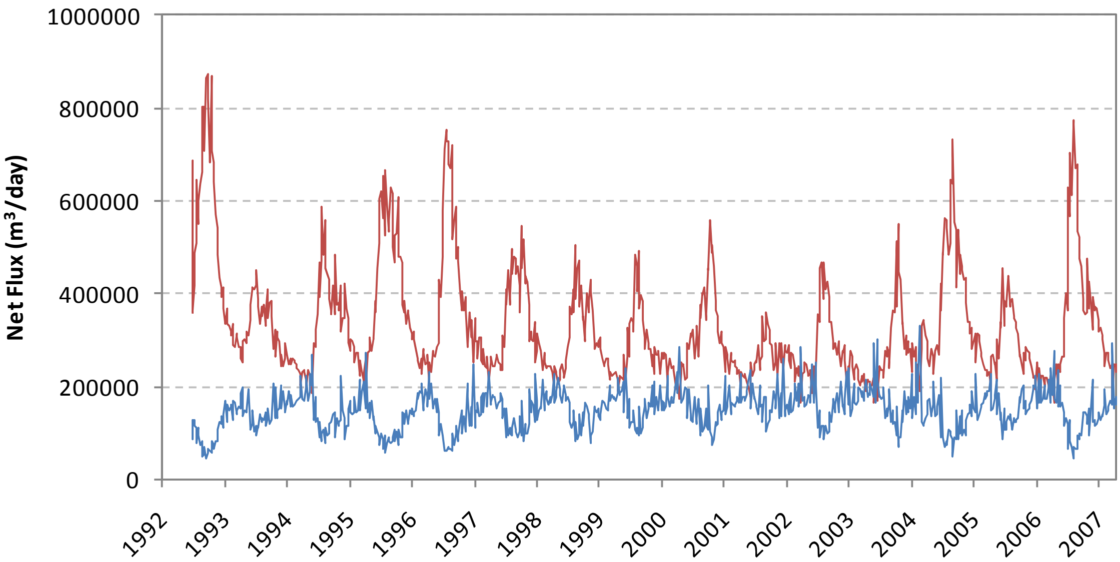

Figure C1: Groundwater baseflow discharge (blue line) and river recharge (red line) calculated for the Middle Valley over the period 1992 to 2006 inclusive

Both the Upper and Lower Valley groundwater models show a similar groundwater baseflow contribution to flow in the Ruamahanga River illustrating the importance of groundwater baseflow in maintaining summer low flows.

C.3 Global pumping scenarios

As described in Appendix B, the riparian Q1 aquifers along the margins of the major river systems in the Wairarapa Valley exhibit a high degree of hydraulic connection with surface water. The potential exists for groundwater abstraction from these aquifers to result in direct stream depletion effects on surface water. In order to characterise the potential impact of abstraction from the Q1 aquifers, several model scenarios were run to simulate the potential effect on surface water resulting from simulated historical pumping in the Wairarapa Valley.

Figure C2 shows the modelled stream depletion resulting from existing groundwater abstraction in the Middle Valley catchment over the period 1993 to 2007. The graph shows two curves which indicate the calculated stream depletion effect resulting from pumping of all groundwater abstraction consents (blue shading) compared to that resulting from those takes located in the Q1 gravels only (green shading). Results of this scenario illustrate two important considerations for the overall management of cumulative stream depletion effects:

- Stream depletion from riparian (Q1) aquifers only makes up a proportion (in this case <50%) of the total cumulative effect on surface water. Therefore a framework to manage cumulative stream depletion effects needs to take into account both the direct effects from takes with a high degree of connectivity with surface water and the cumulative reduction in baseflow resulting from takes with a lower degree of hydraulic connection;

- Stream depletion effects from abstraction in Q1 aquifers dissipate rapidly once pumping stops compared to the more gradual reduction occurring from groundwater takes with a lower degree of hydraulic connectivity. As a result, while stream depletion effects from the Q1 aquifers can be managed (or at least mitigated) by pumping regulation during low flow periods similar controls on groundwater takes with a lower degree of hydraulic connectivity are unlikely to be an effective means of mitigating effects on river and stream flows.

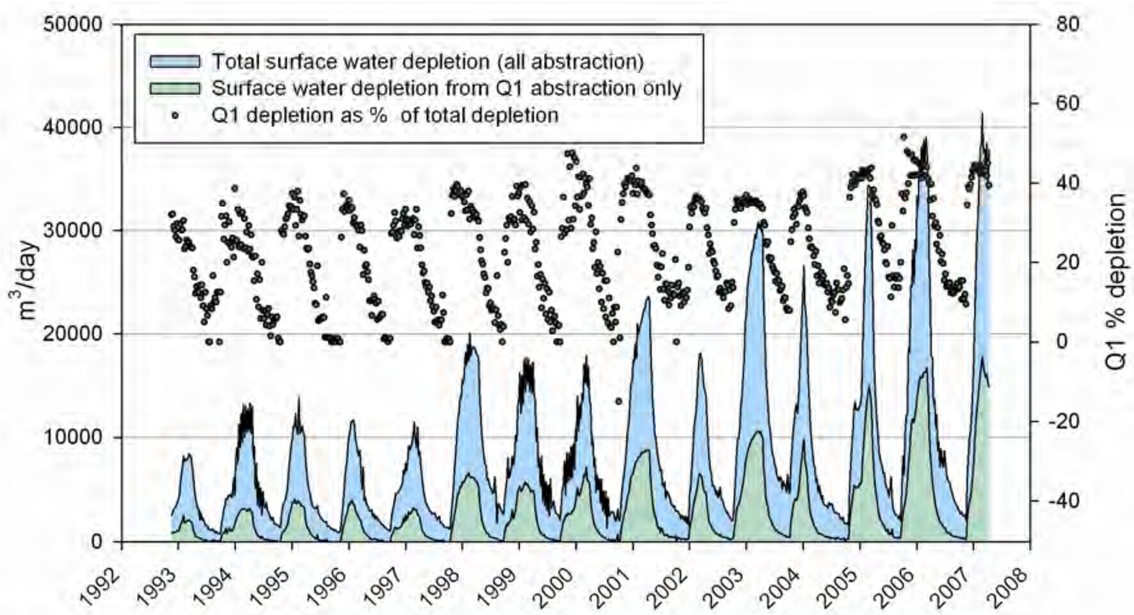

Figure C2: Modelled surface water depletion resulting from groundwater abstraction for the whole of the Middle Valley catchment

Figure C3 shows a plot of the calculated rate of stream depletion resulting from groundwater abstraction from the shallow (Q1) aquifers along the riparian margin of the Waiohine River compared to the overall rate of abstraction over the period 1992 to 2007. The figure clearly shows that the overall stream depletion effect (including impacts on the Waiohine River and Greytown springs) approximates the rate of groundwater abstraction (q/Q ~1)[25] with limited lag between abstraction and effects on surface water[26]. Correspondingly, the plot also shows the rate of stream depletion reduces rapidly once pumping ceases.

[25] q/Q refers to the ratio of direct stream depletion (q) to the overall pumping rate (Q)

[26] It is noted that the calculated stream depletion effect in the pumping scenario illustrated actually exceeds the rate of abstraction – this is due to the effects of abstraction from surrounding alluvial fan aquifers.

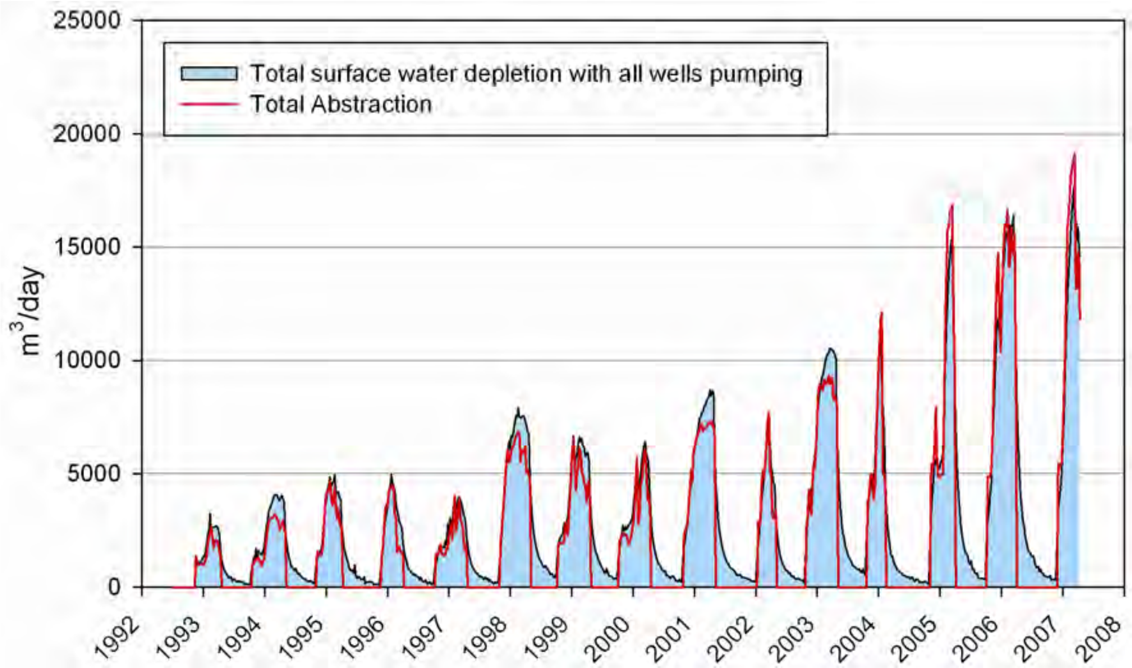

Figure C3: Calculated rate of stream depletion resulting from groundwater abstraction from the Waiohine zone, 1992-2007

Figure C4 shows a similar plot for groundwater abstraction in the Middle Ruamahanga water management zone. Again the plot shows that for all bores (both those screened in the shallow Q1 alluvial (<10 m) and deeper Q2 gravels (10 to 30 m)) within the relatively narrow (<4 km wide) alluvial valley, stream depletion effects develop rapid following the commencement of pumping and quickly reach a level close to the overall rate of abstraction.

Figure C5 shows an expanded view of the calculated stream depletion effect during a nominated irrigation season (2000/01) and shows that the depletion curves from both the Q1 and Q2 aquifers closely follow the overall rate of groundwater abstraction with a slightly reduced magnitude (in terms of q/Q) and longer lag time for the Q2 pumping. It is again noted that the calculated stream depletion curve for Q1 abstraction closely matches the modelled abstraction rate (i.e. q/Q ~1).

Global abstraction scenarios run for pumping from shallow unconfined alluvial aquifers along the riparian margins of the major rivers in other areas of the Wairarapa Valley show similar results to those illustrated for the Waiohine and Middle Ruamahanga water management zones. In all areas q/Q values rapidly approach the overall pumping rate once pumping commences and decline relatively quickly once pumping stops reflecting the high degree of connectivity between groundwater and surface water. Overall, the global model scenarios clearly illustrate:

- Groundwater abstraction from the shallow unconfined Q1 aquifers along the margins of the main rivers has a direct and immediate effect on surface water by reducing flows at a rate that quickly approaches the overall rate of groundwater abstraction; and,
- Stream depletion effects dissipate rapidly once pumping ceases.

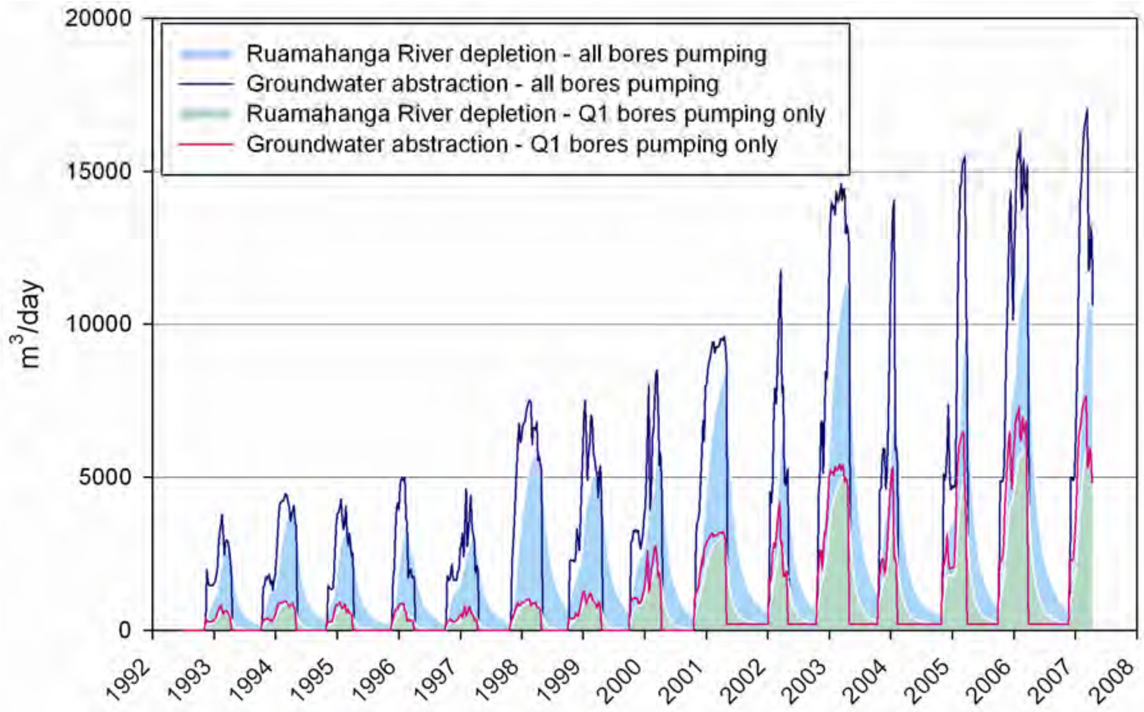

Figure C4: Calculated stream depletion resulting from groundwater abstraction in the Middle Ruamahanga zone separated into pumping from shallow Q1 (<10m) and deeper Q2 (>10 m) aquifers

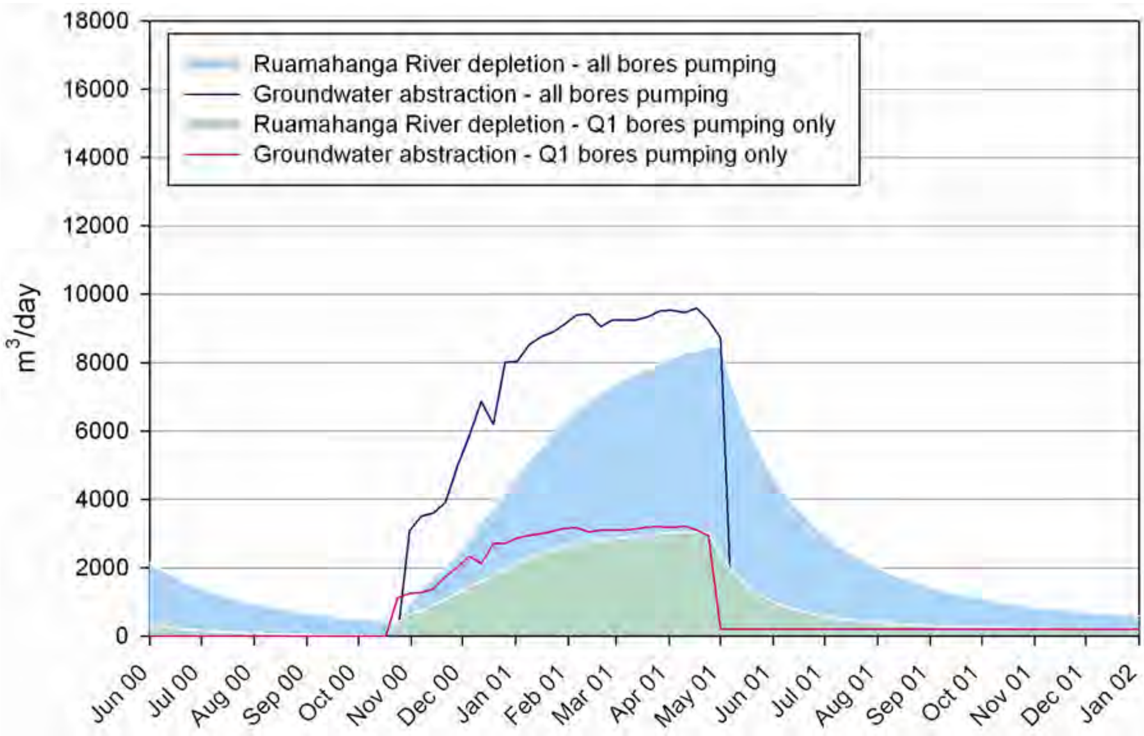

Figure C5: Calculated stream depletion in the Middle Ruamahanga zone resulting from groundwater abstraction over the 2000-01 irrigation season

Overall, these model scenarios demonstrate that groundwater takes from the Q1 aquifers (and the Q2 deposits in the Middle Ruamahanga valley) can effectively be managed as equivalent surface water takes in order to control direct effects on surface water.

However, outside the unconfined riparian aquifers, global pumping scenarios indicate the groundwater abstraction has a less immediate and more indirect effect on surface water flow. For example, Figure C6 shows that groundwater abstraction from the Mangatarere catchment (including Q1 and Q2 aquifers) results in an overall stream depletion effect which approaches 60 to 70 percent of the cumulative pumping rate toward the end of each irrigation season but which lags behind the seasonal pumping rate resulting in a slowly receding depletion rate during the winter months. This lag reflects the reduced hydraulic connectivity between the Q2 alluvial fan aquifers and the Mangatarere Stream.

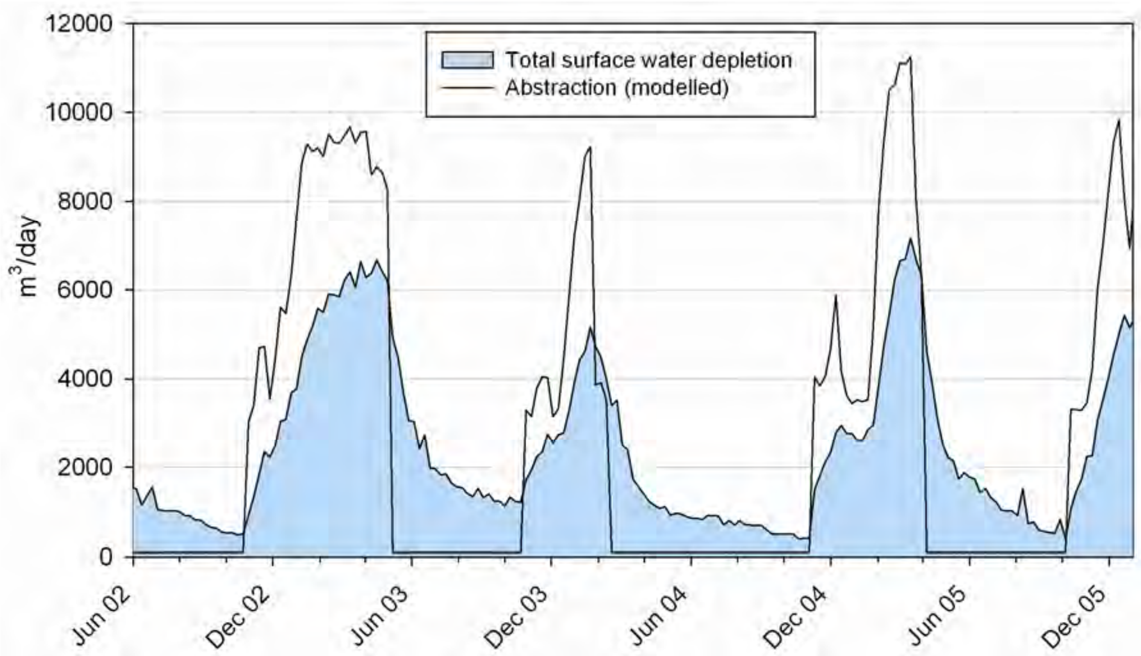

Figure C6: Simulated historical abstraction and associated surface water depletion (including effects on Mangatarere Stream and local spring-fed streams) resulting from groundwater abstraction in the Mangatarere catchment, 2002-05

Figure C7 shows a similar plot for groundwater abstraction in the Parkvale area over the 2000/01 and 2001/02 irrigation seasons. In this case, calculated surface water depletion resulting from groundwater abstraction reaches a maximum of less than 25% of the overall abstraction rate but continues for a considerable period following the cessation of pumping. This reflects the moderate hydraulic connectivity of groundwater in this area (particularly the semi-confined Q6 and Q8 aquifers) to surface water.

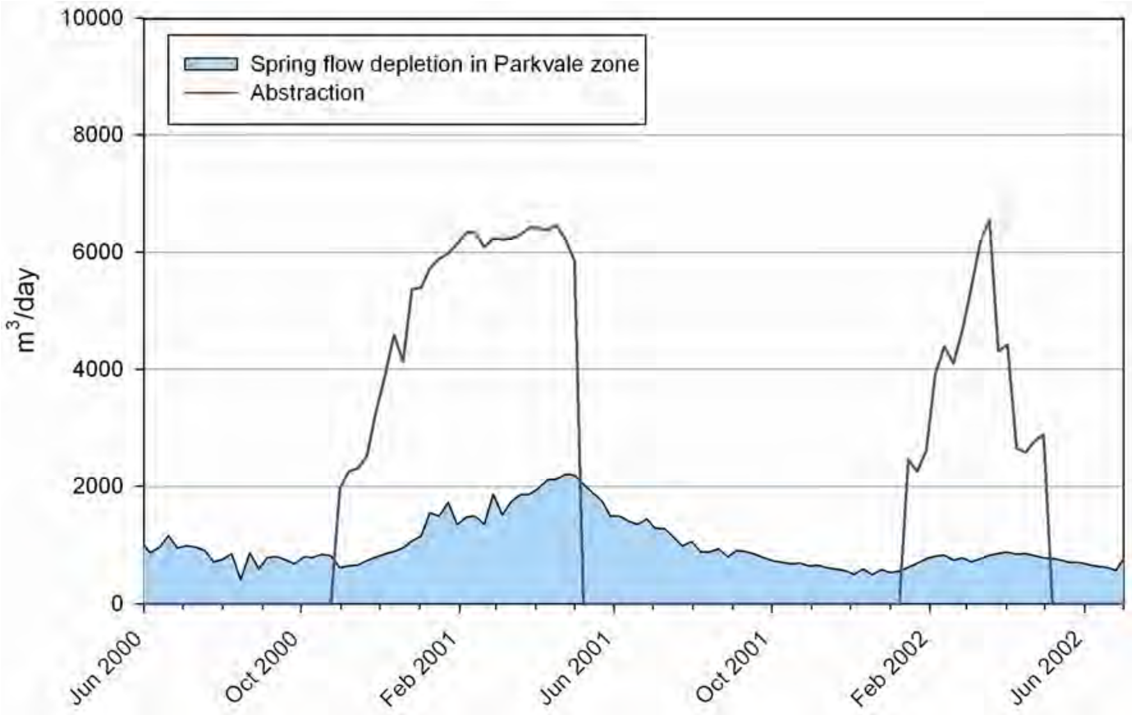

Figure C7: Simulated historical abstraction and associated surface water depletion in the Parkvale area, 2000-02

In the pumping scenario from the Mangatarere catchment illustrated in Figure C6, stream depletion effects dissipate relatively slowly following the cessation of pumping with the overall rate of decline depending on seasonal recharge (i.e. the higher winter rainfall recharge, the quicker stream depletion effects dissipate). As a result, it is unlikely that pumping regulation (i.e. minimum flow cut-offs) will be an effective means of mitigating the effects of groundwater abstraction on surface water during periods of low flow for all groundwater takes in this area. This type of hydrogeological setting would fit into the proposed Category B classification where minimum flow controls would be imposed only where they were warranted by the degree of hydraulic connection assessed for an individual groundwater take.

In the case of the Parkvale scenario illustrated in Figure C7 groundwater abstraction is primarily derived from groundwater storage and modelled stream depletion effects comprise a relatively low percentage of the overall pumping rate (exhibit a significant lag with seasonal pumping cycles). In this type of hydrogeological setting pumping regulation is clearly unlikely to provide an effective means of managing effect on surface water. However, despite the long lag time, the effects of abstraction from deeper aquifers in the Parkvale area may still make a significant contribution (in the example illustrated up to 2,000 m^3/day) to the overall depletion of baseflow discharge at a catchment scale. Under the management framework proposed in Section 2, this type of hydrogeological setting would be classified as Category C where the cumulative effects of groundwater abstraction on baseflow discharge are accounted for in terms of a total volumetric groundwater allocation limit established for the Parkvale water management zone.

C.4 Individual pumping scenarios

In order to characterise the potential nature of stream depletion effects around the margins of the major rivers, a series of pumping scenarios were analysed using both the numerical models and analytical techniques. These scenarios involved the simulated pumping of an individual bore at varying distances and depths along a transect perpendicular to the river channel to determine the way in which potential direct stream depletion effects vary spatially. This information was used to identify the potential extent of the Category A and B areas across the various water management zones fully detailed in Appendix D to F.

Figure C8 shows the results of individual pumping scenarios for the Q1 aquifer along the riparian margin of the Waiohine River in the Greytown area. The scenarios illustrated show the calculated stream depletion effect resulting from abstraction at a rate of 3,000 m^3/day for a period of approximately 150 days from shallow (<10m) bores situated 500, 1000 and 2000 metres from the Waiohine River[27]. The calculated stream depletion is the cumulative effect on both the Waiohine River and the Papawai Springs. The mode results indicate that regardless of position within the Q1 gravel aquifer, groundwater abstraction results in immediate and significant stream depletion effects which represent a significant proportion of the overall rate of groundwater abstraction (q/Q >0.8) after pumping for an extended duration.

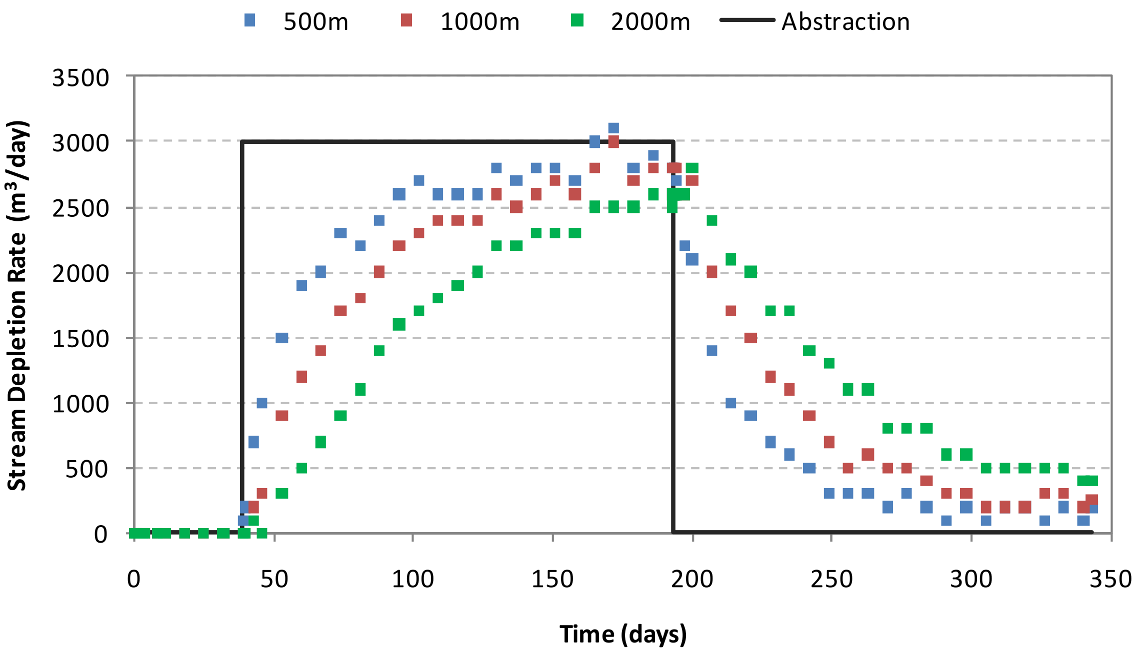

Figure C8: Results of pumping scenarios for the Q1 aquifer along the riparian margin of the Waiohine River

The short time-lag between abstraction and effects on surface water and the significant magnitude of the overall stream depletion effect reflects the high degree of connectivity with surface water. This suggests that Q1 aquifers, such as the Waiohine floodplain, have limited effective storage capacity, with aquifer water balance rapidly equilibrating to groundwater abstraction through a combination of increased river flow loss and

27 The pumping rate and duration chosen for the individual scenarios were chosen to represent a 'typical' pumping regime provided for by conditions on existing resource consents which specify a maximum instantaneous and/or daily abstraction rate and seasonal allocation.

decreased baseflow. These results are consistent with the global model scenarios and suggest that for aquifer systems such as the Waiohine Q1 gravels that it is reasonable to manage groundwater takes from these aquifers as equivalent surface water takes.

Figure C9 shows a plot comparing the calculated stream depletion from the Waiohine River for the 500 metre numerical model pumping scenario against that calculated using the Hunt (1999) analytical solution utilising roughly equivalent hydraulic parameters. The graph shows general agreement between the two methods but highlights some of the difficulties applying simple analytical solutions to complicated real-world situations. The graph suggests that the analytical method may over-predict effects on the Waiohine River but under predict the total stream depletion effect because it does not take into account potential effects on the Greytown. However, the comparison does show that, provided reasonable hydraulic parameters are utilised, analytical assessment methodologies can provide a useful means to quantify the approximate magnitude of stream depletion effects in this type of hydrogeological setting.

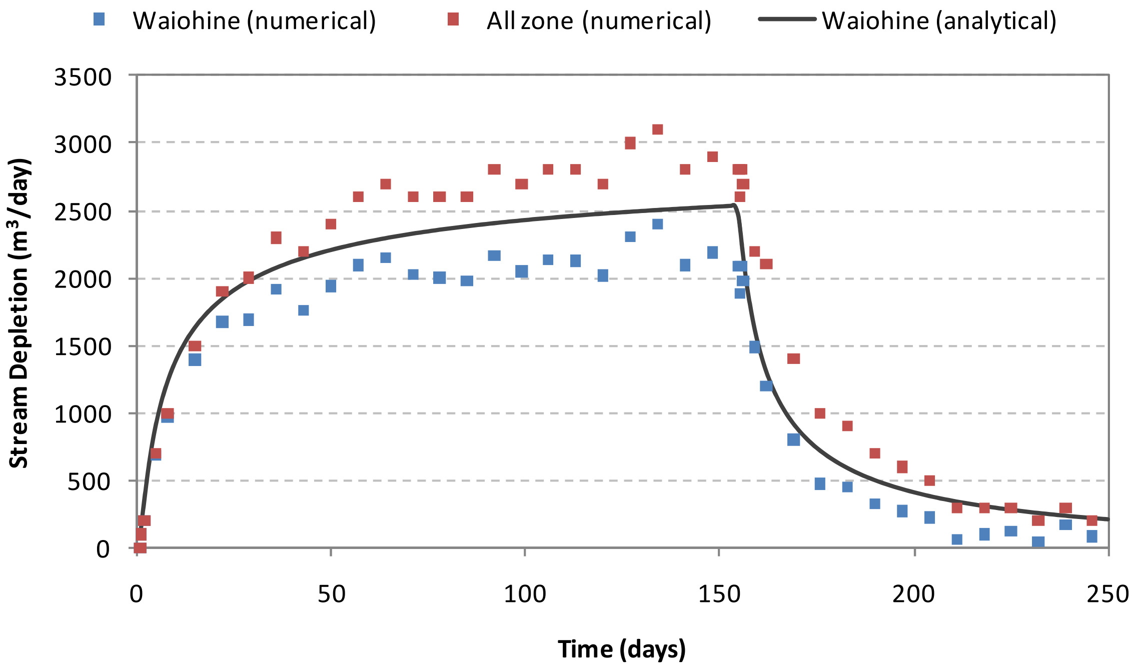

Figure C9: Comparison of stream depletion calculated for the Waiohine 500 metre pumping scenario using analytical and numerical models

In other areas of the Wairarapa Valley, where the spatial extent of the Q1 gravels is not as extensive as along the Waiohine River, the magnitude of calculated stream depletion effects declines relatively quickly beyond the Q1/Q2 boundary. For example, Figure C10 shows results of individual pumping scenarios along a transect running east of the Tauherenikau River. In this example, calculated stream depletion effects are relatively significant (q/Q >0.7) within the Q1 gravels extending out to a distance of approximately 1,500 metres from the river, but decline relatively rapidly beyond this point reflecting the lower hydraulic conductivity of the Q2 gravels.

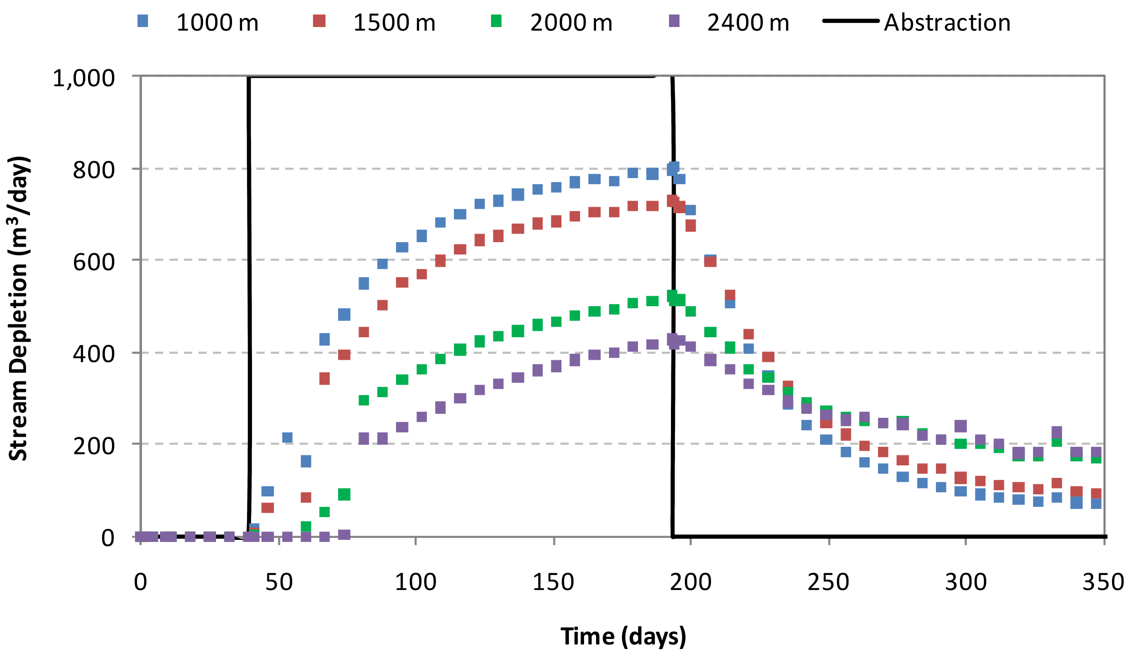

Figure C10: Results of individual pumping scenarios along the riparian margin of the Tauherenikau River

Individual pumping scenarios for the Mangatarere catchment shown in Figure C11 also show a similar effect, with a decreasing magnitude and increased lag with distance from the river channel. In the example shown, the calculated stream depletion effect from the 500 m bore (located within the Q1 gravels) is relatively significant (q/Q ~0.7) but drops of rapidly in the 1,200 m (q/Q ~0.5) and 1,800 m (q/Q ~0.3) bores (located in Q2 alluvial fan aquifers 330 m and 940 m respectively from the Q1/Q2 boundary).

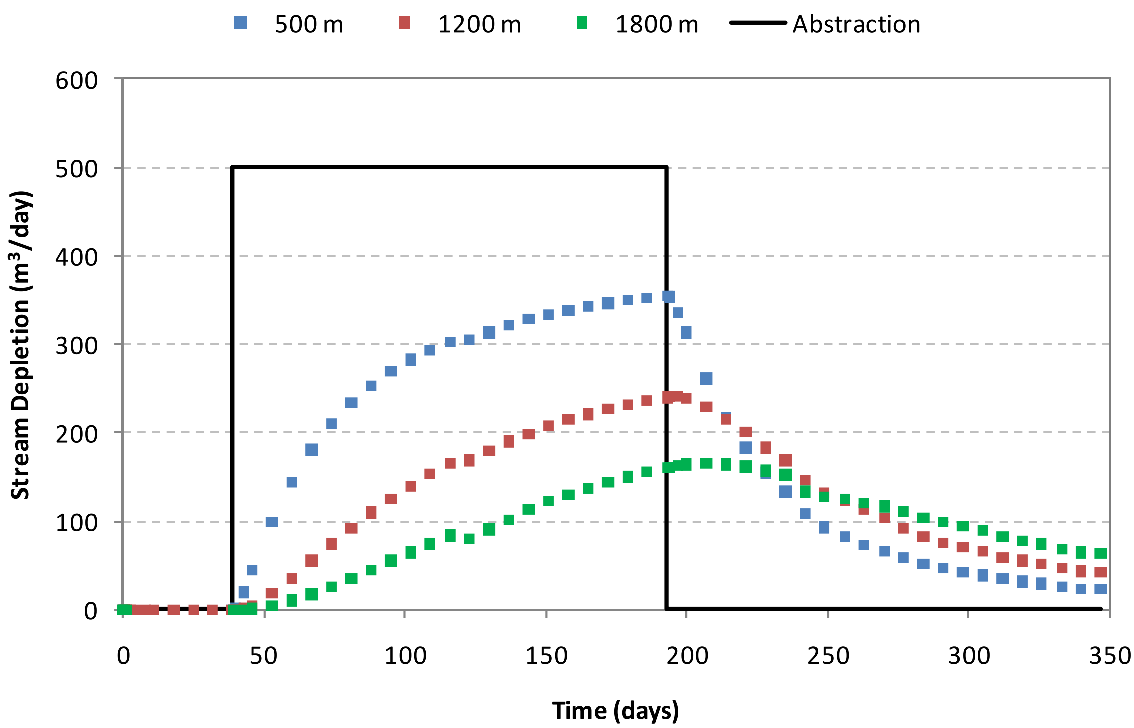

Figure C11: Individual pumping scenarios for the Mangatarere catchment

Both the Tauherenikau and Mangatarere scenarios illustrate the transition from direct and immediate effects on surface water to more indirect effects as groundwater abstraction moves from the recent, high permeability (typically Q1) alluvial gravels along the channel margins to the surrounding lower permeability alluvial fan deposits (typically Q2 or older). Thus there is an area along the outer margin of the Q1 aquifers where stream depletion effects may or may not be determined to be significant depending on localised factors (e.g. aquifer hydraulic characteristics, distance to the river channel and abstraction rate). Under the proposed management framework outlined in Section 2 of the main report, this transition zone between indirect and direct stream depletion effects would be classified as Category B where pumping regulation may or may not apply depending on local hydrogeological conditions.

Potential differences in the nature and magnitude of stream depletion resulting from abstraction from deeper semi-confined aquifers compared to that from shallow unconfined aquifers is illustrated by comparison of the pumping scenarios illustrated in Figure C12 and Figure C13. Figure C12 shows the modelled stream depletion effect resulting from groundwater abstraction at a rate of 2,000 m^3/day from a bore screened in the unconfined (Q1) aquifer approximately 2,500 m east of the Ruamahanga River in the Te Ore Ore basin. Figure C13 shows a similar plot for a scenario involving abstraction at the same rate and location from the deeper semi-confined aquifer (34 m) and shows a virtually identical potential depletion effect to that modelled for the shallow pumping scenario reflecting the relatively ‘leaky’ nature of the semi-confined aquifers in this area.

In this example, due to the relatively leaky nature of the aquifer system, pumping from the deeper water bearing layer results in a minimal reduction in the overall magnitude of stream depletion (q/Q 0.88 from shallow pumping compared to 0.82 for the deeper abstraction). However, the model results do indicate some changes both in the relative contribution of flow loss from individual surface waterbodies and in the overall shape of the various stream depletion curves, reflecting the differing storage characteristics in the unconfined and semi-confined aquifers.

Overall, the Te Ore Ore pumping scenarios indicate that it is reasonable to manage both the shallow unconfined aquifer and upper semi-confined aquifer in the Te Ore Ore basin as a single unit in terms of potential effects on surface water. Results from the Tauherenikau catchment show a similar effect from deeper water bearing layers adjacent to the river across the mid-fan area.

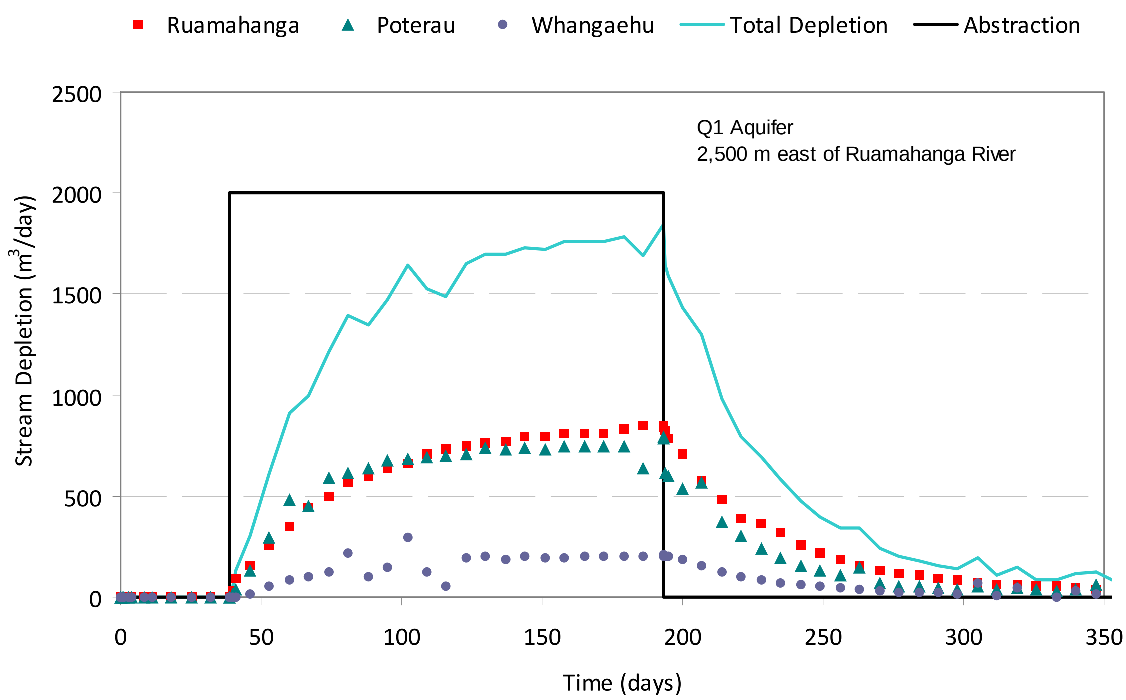

Figure C12: Modelled stream depletion resulting from groundwater abstraction from the shallow unconfined aquifer (Q1) in the Te Ore Ore basin, 2,500 m east of the Ruamahanga River

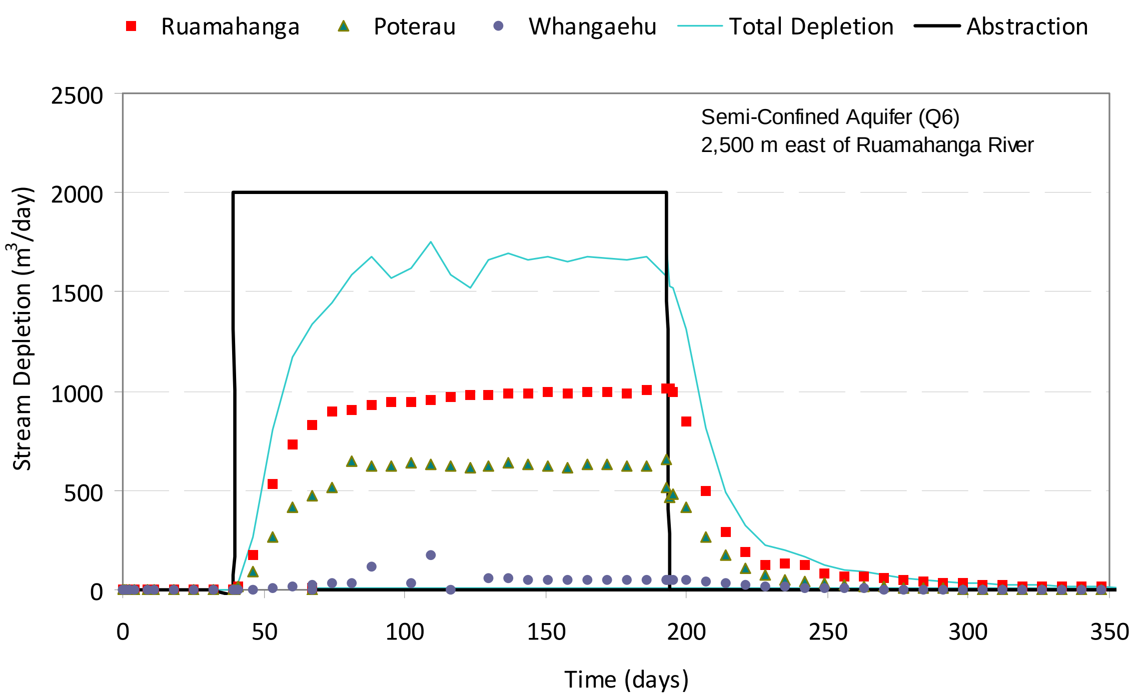

Figure C13: Modelled stream depletion resulting from groundwater abstraction from the upper semi-confined aquifer (Q6) in the Te Ore Ore basin, 2,500 m east of the Ruamahanga River

C.5 Summary

Modelling both global and individual pumping scenarios provides information to characterise the nature and magnitude of potential stream depletion effects resulting from groundwater abstraction across a range of hydrogeological settings in the Wairarapa Valley.

The modelling results clearly illustrate the high degree of hydraulic connection between groundwater and surface water in the Q1 aquifers along the riparian margins of the major rivers and indicate that stream depletion effects resulting from groundwater abstraction from these aquifers can be reasonably managed by application of pumping regulation (i.e. cut-offs) consistent with environmental flows and water levels established for hydraulically connected surface waterbodies.

Model outputs also demonstrate how the potential magnitude of stream depletion decreases and lag times increase as pumping moves across the alluvial fan aquifers away from the major rivers. However, in some areas scenario results also indicate there is limited difference in potential effects resulting from groundwater abstraction from semi-confined aquifers compared to that resulting from equivalent abstraction from overlying unconfined aquifers, due to vertical leakage induced by abstraction from the deeper aquifers.

Appendix D

Appendix D: Upper Valley groundwater allocation framework

This Appendix sets out a framework for the sustainable allocation of groundwater in the Upper Valley catchment of the Wairarapa Valley. It contains a summary of the hydrogeological setting of the Upper Valley as a whole and then discusses potential allocation regimes for each of the management zones within the Upper Valley.

D.1 Summary of Upper Valley catchment hydrogeology

The hydrogeology of the Upper Valley catchment is described in detail by Gyopari and McAlister (2010a). A summary of the key features of the Upper Valley catchment is provided here.

The Upper Valley catchment of the Wairarapa Valley has an area of about 160 km^2 and is bounded by the Waingawa River in the south, the Tararua Range in the north, and the eastern hill country to the south and east. The Ruamahanga River and its main tributaries within the Upper Valley catchment – the Waingawa and Waipoua rivers – are the principal surface water drainage systems in the catchment. Other drainage systems include the Kopuaranga and Whangaehu rivers which drain hill country to the north and east of Masterton respectively. Numerous smaller streams and spring systems also occur on the alluvial fans and plains, many of which exhibit a significant degree of interconnection with local groundwater systems.

A heterogeneous succession of late Quaternary and Holocene unconsolidated sediments comprise the primary groundwater environment of the catchment. Variable degrees of sediment sorting, reworking, compaction and deformation by faulting and folding have resulted in a complex hydrogeological environment. Major structures, such as the Masterton and Mokonui faults, have dislocated and folded the sediment sequence and created the Te Ore Ore sub-basin. Four broad hydrostratigraphic units are present – the most important, in terms of groundwater resource potential, are recent (Holocene age) alluvium connected to major river systems, and older Tararua-sourced alluvium in the Te Ore Ore basin forming a relatively extensive semi-confined aquifer system.

Rainfall infiltration is an important recharge source in the catchment; about 30 to 40% of rainfall recharges groundwater over the western and northern areas of the catchment, while less than 10% of rainfall infiltrates to the underlying water table over the drier eastern parts. The average annual volume of rainfall recharge in the Upper Valley catchment area over the 16 years ending in 2008 is calculated to be of the order of 48 x 10^6 m^3/year (Gyopari and McAlister 2010a). Temporal changes in the dynamics of the groundwater system are attributable to a combination of natural climatic variability and rapidly developing abstraction stresses.

The groundwater flow pattern reflects a system in which rivers interact closely with adjacent riparian aquifers depending on the relative hydraulic gradient. Fluxes between shallow groundwater and surface water dominate the groundwater balance for the Upper Valley catchment. Natural groundwater discharges occur as river baseflow, spring flow and diffuse seepage into wetlands. Some reaches of the main river channels recharge groundwater by losing part of (or sometimes, all of) their flow into adjacent aquifers. Concurrent river gauging surveys show that the three principal river systems – the Ruamahanga, Waipoua and the Waingawa rivers – exhibit complex patterns of flow gain and loss with respect to adjacent shallow aquifers.

Conceptually, the Upper Valley groundwater catchment is characterised as a ‘closed’ groundwater basin in which the dominant water balance components are rainfall recharge and fluxes between surface water and groundwater. The most important hydrogeological characteristic of the catchment is the strong interdependence of surface water and groundwater. The shallow unconfined aquifer is of particular significance since it is freely connected to the surface water environment (rivers, springs and wetlands), particularly along the riparian margins of the major river systems.

D.2 Water management zones

Managing the cumulative effects of groundwater abstractions with a moderate to low hydraulic connection to surface water has been approached by delineating '*water management zones*' within each of the three Wairarapa Valley catchments (Upper, Middle and Lower). These zones are essentially management units based on groundwater and surface water sub-catchment mapping which may also (or alternatively) represent distinct hydrogeological domains. Zone delineation criteria include surface water catchment boundaries, hydraulic or physical groundwater flow system boundaries, the conceptual hydrogeological functioning of the zone and its context within the larger groundwater catchment.

The zones are designed so that the management of surface water resources can be easily integrated with groundwater allocation, thereby allowing the cumulative effects of groundwater abstraction on sub-catchment baseflow to be accounted for at a catchment scale (i.e. enabling conjunctive management of groundwater and surface water resources).

It is important to recognise the water management zones are not, in most instances, isolated management units. Most zones have 'soft' boundaries based on hydraulic divides or represent transitional areas within a continuous groundwater flow system. Where significant interactions between zones are recognised, the sensitivity of cross-zone groundwater fluxes to the cumulative effects of abstraction has been evaluated and provision made in the allocation options.

Figure D1 shows the spatial distribution of the three 'water management zones' for the Upper Valley catchment which are summarised in Table D1. The zones are based primarily upon surface water and groundwater catchments, but are also locally constrained by geological boundaries. The delineation of water management zones is therefore based upon the conceptual hydrogeological model and recognition of distinct hydrogeological domains. The rationale behind each zone boundary is provided in the relevant management zone sections.

Table D1: Water management zones, management objectives and criteria for the Upper Valley catchment

Zone name	Area (km^2)	Management objectives	Allocation criteria
Te Ore Ore	27.1	Baseflow depletion: Ruamahanga River Poterau Stream	Low flow in Ruamahanga River. 2. Poterau Stream 3. Recharge
Waingawa	77.7	Baseflow depletion: Waingawa River Waipoua River Masterton springs.	1. Combined low flow for: - Waingawa River - Waipoua River - Masterton springs 2. Recharge
Upper Ruamahanga	72.0	Baseflow depletion: Ruamahanga River Waipoua River	1. Recharge

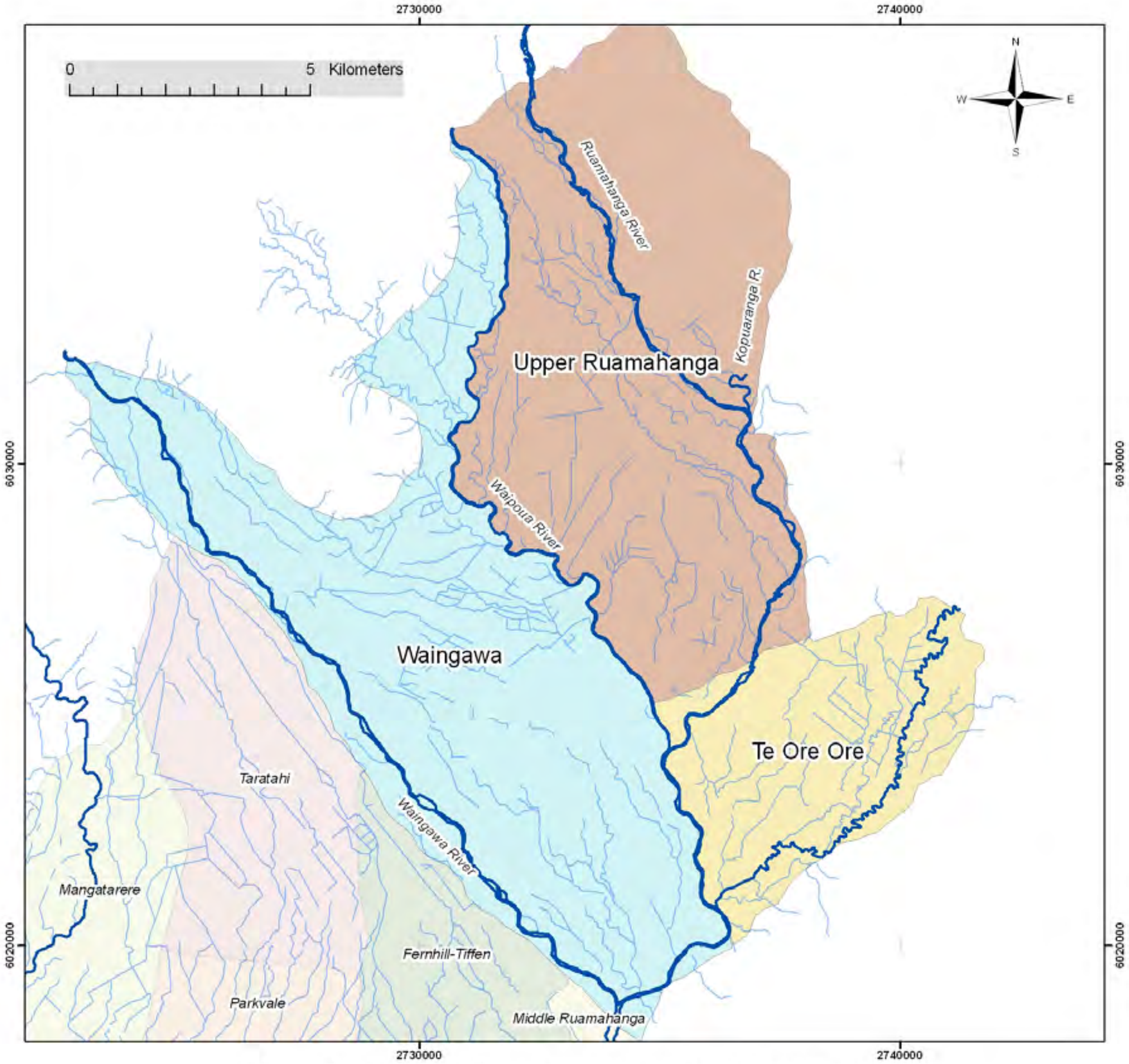

Figure D1: Water management zones in the Upper Valley catchment

Figure D2 shows the existing Regional Freshwater Plan (RFP) (WRC 1999) groundwater management zones and an outline of the new water management zones to enable cross-referencing.

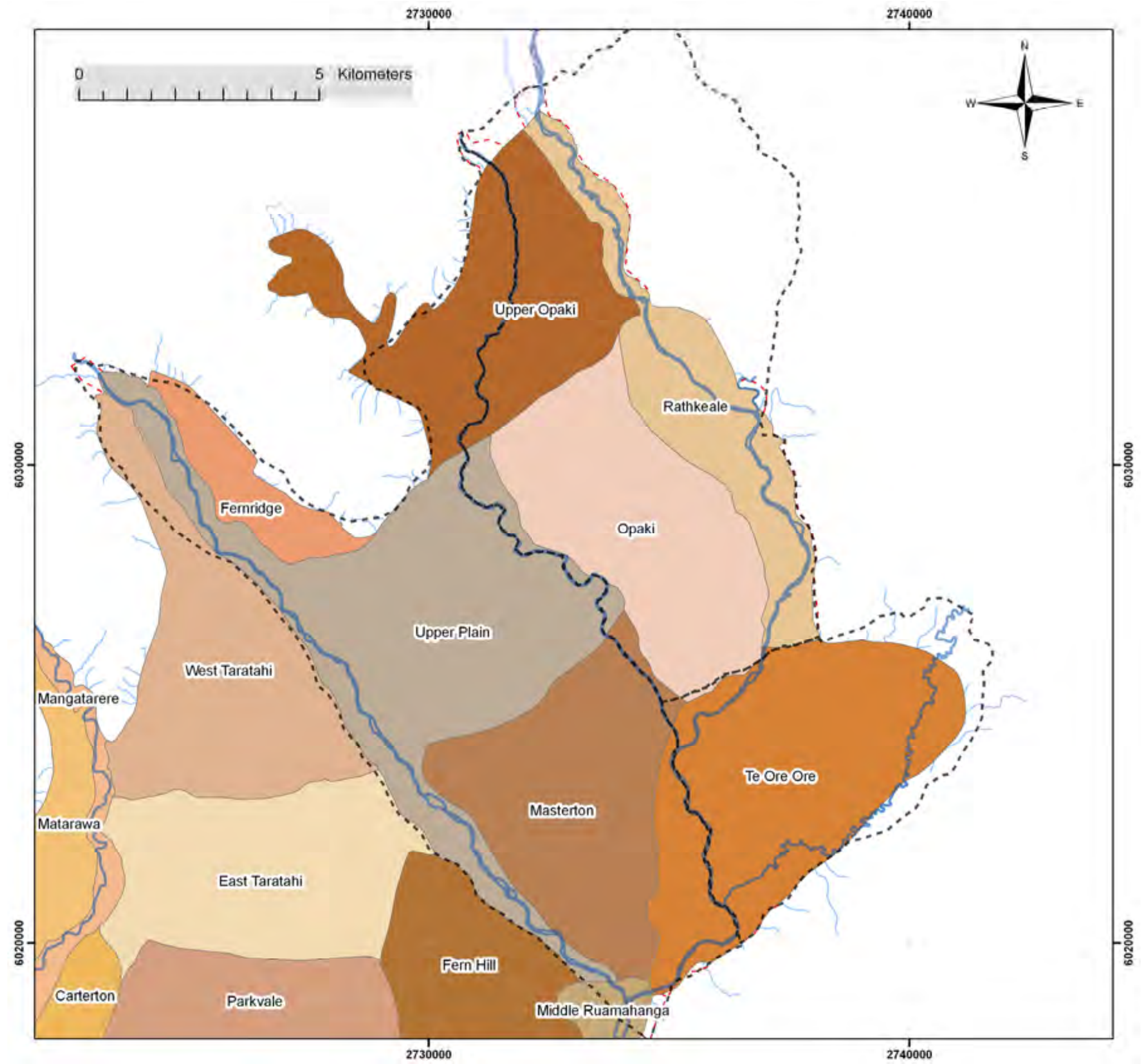

Figure D2: Map showing existing RFP (WRC 1999) groundwater management zones in the Upper Valley catchment and an outline of the new water management zones (black dashed lines)

D.3 Upper Valley catchment numerical groundwater model

The numerical groundwater flow model for the Upper Valley catchment was used to explore groundwater management options for each water management zone by simulating the effects of abstraction on zonal water balances, particularly groundwater-surface water fluxes using various abstraction scenarios. The model provided information on surface water depletion effects, aquifer drawdowns, zone rainfall recharge characteristics, and cross-zone throughflow changes associated with groundwater abstractions. Details of the model and its calibration are provided in Gyopari and McAlister (2010a).

Initially, the numerical groundwater flow model was used to quantify the natural water balances by running the model for the 16-year calibration period (1992 to 2008) with no groundwater abstraction occurring. This scenario provided a ‘baseline simulation’ against which the effects of abstraction were evaluated, including assessment of the cumulative depletion effects of groundwater pumping on the surface water environment and cross-zone throughflow changes. For some sub-catchments, additional scenarios were evaluated to quantify the response of the groundwater system to abstraction and assist refinement of the spatial (and depth) distribution of the various hydraulic connectivity zones described in Sections 3 and 4 of the main report. These scenarios are documented in the following sections.

D.4 Te Ore Ore water management zone

D.4.1 Overview

Delineation: The Te Ore Ore zone defines a discrete local groundwater sub-basin containing a heterogeneous sequence of late Quaternary sandy and silty gravels extending to at least 100 m depth. The edges of the basin are geologically and hydraulically well-defined (Figure D3).

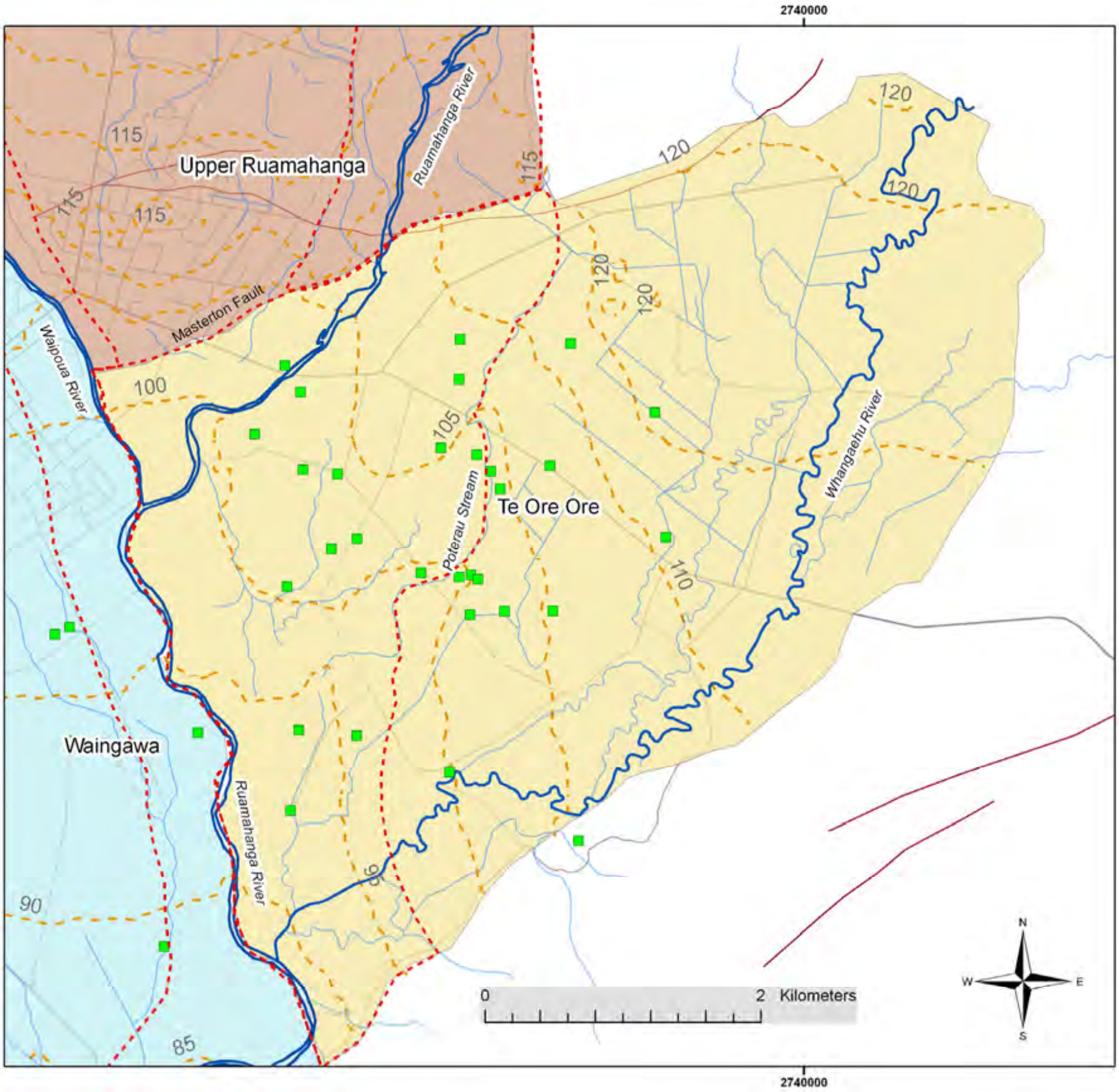

Figure D3: The Te Ore Ore water management zone map showing existing groundwater bores with consented abstraction (green squares) and simulated groundwater flow contours (brown dashed lines, 5 m intervals in metres above mean sea level). The extent of the aquifer system classified as Category A (direct hydraulic connection) is illustrated by the dashed red line.

Area: 27.1 km^2.

Boundaries: The zone boundaries approximate the edges of the Te Ore Ore groundwater sub-basin. The northern boundary follows the Masterton Fault and the western boundary tracks the centreline of the Ruamahanga and Waipoua rivers where the basin deposits merge with the alluvial fans formed by the Waingawa and Waipoua rivers.

Other boundaries follow the contact between the basin-fill late Quaternary alluvium and the elevated eastern hills Tertiary sequence.

Principal surface water systems: Ruamahanga River, Poterau Stream, Waipoua River, Whangaehu River

Aquifer sequences: Single leaky heterogeneous aquifer system

Recharge: Average annual recharge = 4.4 x 10^6 m^3.

Existing RFP zones: Te Ore Ore (Aquifers 1, 2 and 3). The current allocation status of each of these zones is shown in Table D2.

Table D2: 'Safe yield' estimates and current groundwater allocation for existing RFP (WRC 1999) groundwater zones located in (or partially within) the Te Ore Ore water management zone

Existing RFP zone	'Safe yield' (m^3/year)	Current allocation (m^3/day)	% allocated
Te Ore Ore			
- Aquifer 1 (8 consents)	1.3 x10^6	8,043	38
- Aquifers 2+3 (24 consents)	3.0 x10^6	21,300	100

D.4.2 Current consented groundwater abstraction from the Te Ore Ore water management zone

As at June 2010, there are 29 consented groundwater takes from the Te Ore Ore zone with a total daily allocation of approximately 26,700 m^3/day (bore locations shown in Figure D3). Most of the abstraction (24 bores) occurs from the more productive semi-confined aquifers at 20 to 40m depth which have a total allocation of approximately 21,000 m^3/day. The remaining abstraction occurs from very shallow bores generally less than 10 m deep.

D.4.3 Hydrogeology summary

A localised Quaternary age depositional basin lies beneath the Te Ore Ore plain located to the east of Masterton and covering an area of about 2,400 ha. The basin is bounded to the south by Tertiary hill country, to the north by the Masterton Fault and to the west by the edge of the alluvial fans formed by the Waingawa and Waipoua rivers. The Ruamahanga River is roughly coincident with the latter boundary. Geophysical surveying indicates that the basin has a very steep south-eastern side and is at least 100 m deep (to the top of underlying Tertiary mudstone and limestone).

A shallow highly heterogeneous unconfined aquifer occurs between about 5 and 15 m depth. Beneath this, there is a prevalence of bore screens in the 20-30 m depth range in the central part of the basin, shallowing to 10 to 20 m on the western side. Few bores are screened deeper than about 40 m. There is an increased proportion of fine-grained sediment on the eastern side of the basin which is attributed to sediment deposited by the Whangaehu River which drains headwaters dominated by Tertiary mudstone. The central part of the Te Ore Ore basin represents a mergence zone of Tararua-sourced alluvium deposited by the Ruamahanga River, and Eastern Hill-sourced alluvium deposited by the Whangaehu River. The boundary is a broad zone which has probably migrated across the basin over time. Although the sediment sequence is stratified, there are no laterally persistent lithological units, including aquitards. The basin fill is therefore regarded to be a single heterogeneous hydrostratigraphic unit with aquifer conditions ranging from unconfined near to the surface (particularly in south and west), through to leaky-confined at depth. This concept is supported by groundwater level and hydrochemistry data. The western side of the basin (west of the Poterau Stream which appears to follow a terrace edge) is considered to be more permeable and ‘leaky’ with a high degree of connectivity to the Ruamahanga River.

Recharge to the Te Ore Ore aquifers takes place through a combination of rainfall and Ruamahanga River recharge with all aquifers showing a relatively high degree of connectivity to surface water. Discharge from the Te Ore Ore basin is inferred to occur primarily via spring discharge to the Poterau Stream and discharge to the Ruamahanga River upstream of the Whangaehu River confluence.

D.4.4 Hydrology

The Ruamahanga River is the principal drainage system in the Te Ore Ore zone and forms its western boundary. The river has a mean flow of about 24 m^3/s at the Wardell’s bridge gauge site and the 7-day MALF is 3.07 m^3/s. The Ruamahanga River emerges onto the Wairarapa plains at Mt Bruce, about 21 km north of Masterton and is joined by the Waipoua River in Masterton (the Te Ore Ore zone boundary follows a short reach of the Waipoua River immediately upstream of its confluence with the Ruamahanga River).

Concurrent gauging surveys on the Ruamahanga River show a complex spatial pattern of flow losses and gains with a gradual downstream increase in flow between the Mokonui Fault and the Waingawa River confluence (measured at about 1.2 m^3/s). The Masterton Fault does not appear to have any significant influence on the observed pattern of flow gain/loss.

The Whangaehu River follows the southern edge of the Te Ore Ore plain in a perched channel that remains distorted and tightly meandering. The mean flow of the Whangaehu River, in its middle reaches, is only 0.54 m^3/s and the mean annual low flow is 0.018 m^3/s. The river does not appear to interact significantly with the underlying unconfined aquifer system (possibly due to the fine-grained nature of the streambed sediments which reflect the predominantly mudstone geology in the catchment headwaters).

The Poterau Stream flows across the centre of Te Ore Ore plain (Figure D3) and is largely spring-fed from the underlying gravel aquifer. The stream is located along the boundary between silt-rich alluvium sourced from the Whangaehu catchment and more gravel-rich alluvium associated with the Ruamahanga River. There are very few gauging data available for the stream. Flows are highly seasonal, with negligible flow occurring during the summer months (although evapotranspiration may consume most of the discharge before it reaches the confluence with the Whangaehu River). Anecdotal reports suggest there has been a noticeable reduction in summer flows in recent years which appears to coincide with the development of the groundwater resource for seasonal irrigation. The numerical groundwater model (Gyopari and McAlister 2010a) predicted a natural summer discharge of about 100 L/s in the stream, gradually declining to about 50 L/s over the 16-year simulation period.

D.4.5 Zone management objective

The principal management objective for groundwater allocation in the Te Ore Ore zone is to ensure the sustainable use of groundwater resources while protecting the instream values of hydraulically connected surface water ecosystems.

Within the Te Ore Ore zone, the Ruamahanga River and Poterau Stream have a direct connection to the groundwater environment and the protection of baseflow in these systems is of primary importance.

D.4.6 Numerical modelling

The calibrated groundwater model for the Upper Valley catchment was used to assess the sustainability of current groundwater abstractions and appropriate allocation options for the Te Ore Ore zone. Details of the model and its calibration are provided in Gyopari and McAlister (2010a).

Baseline (no-abstraction) water balance

The numerical groundwater flow model was used to quantify the natural water balance for the Te Ore Ore zone by running the model for a period of 16 years (1992 to 2008) with no abstraction occurring. This scenario provided a baseline simulation against which the effects of abstraction were evaluated. Of particular relevance to assessing the sustainability of abstraction, the model provides information on the cumulative depletion effects of groundwater pumping on the surface water environment.

The principal water balance components for the Te Ore Ore zone are rainfall recharge and groundwater-surface water fluxes in relation to the Ruamahanga River and the Poterau spring system. Figure D4 shows the modelled annual rainfall recharge for the Te Ore Ore zone for the period 1992 to 2008. The average annual rainfall recharge is calculated as 4.4 $x10^6$ m^3 (although it is noted there is a significant degree of inter-annual variability in the recharge which may be in excess of 50% of the mean). The lower quartile annual recharge for this dataset is 1.8 x 10^6 m^3/year.

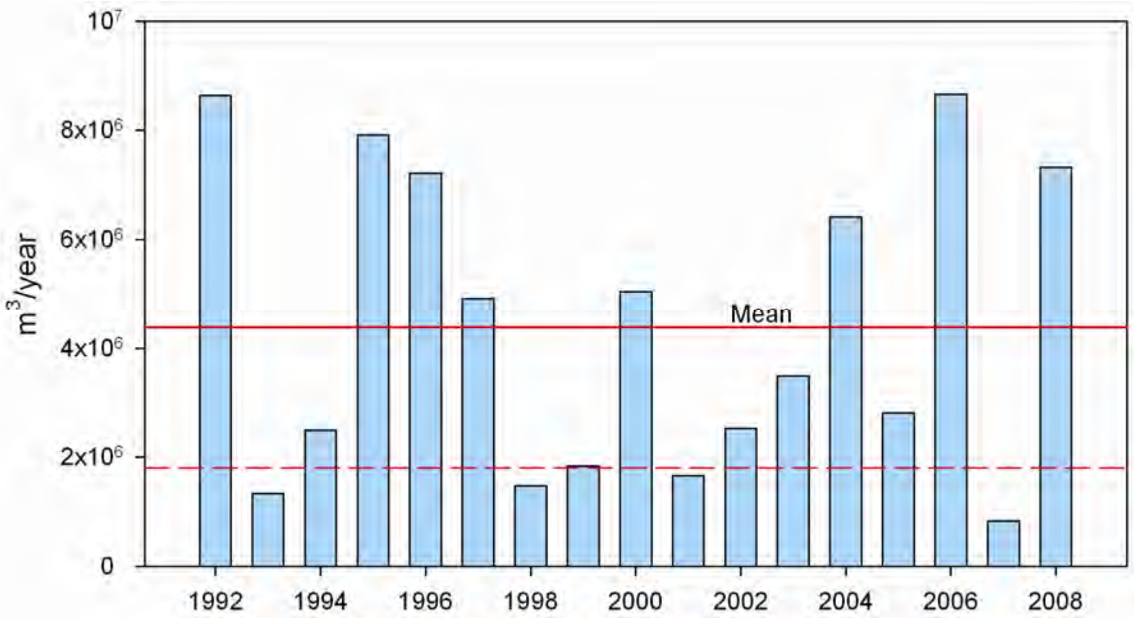

Figure D4: Modelled annual rainfall recharge for the Te Ore Ore zone in the Upper Valley catchment between 1992 and 2008. A mean recharge of 4.4 x 10^6 m^3/year is indicated as is the lower quartile value of 1.8 x 10^6 m^3/year (dashed line).

D.4.7 Modelled abstraction effects 1992–2008

Abstraction from the Te Ore Ore zone was simulated for the 16-year transient model run (Figure D5). Seasonal abstraction in this area has increased significantly since 1999 and peaked at approximately 16,000 m^3/day (estimated abstraction) over the 2007/08 irrigation season. The current consented abstraction is about 27,000 m^3/day and actual use is estimated as approximately 60% of the consented daily rate.

The modelled depletion effects of estimated abstraction on the surface water environment are shown in Figure D6. This plot shows simulated depletion of the Ruamahanga River and Poterau Stream resulting from historical abstraction from all consented bores in the Te Ore Ore zone. The model predicts that the total seasonal depletion (Poterau + Ruamahanga depletion) is almost equivalent to the abstraction rate thereby suggesting an overall high degree of connectivity between the Te Ore Ore aquifers and the surface water environment. During some years, the depletion rate appears to exceed the pumping rate because some of the depletion shown can be attributed to cross-boundary effects resulting from groundwater abstraction from adjacent water management zones.

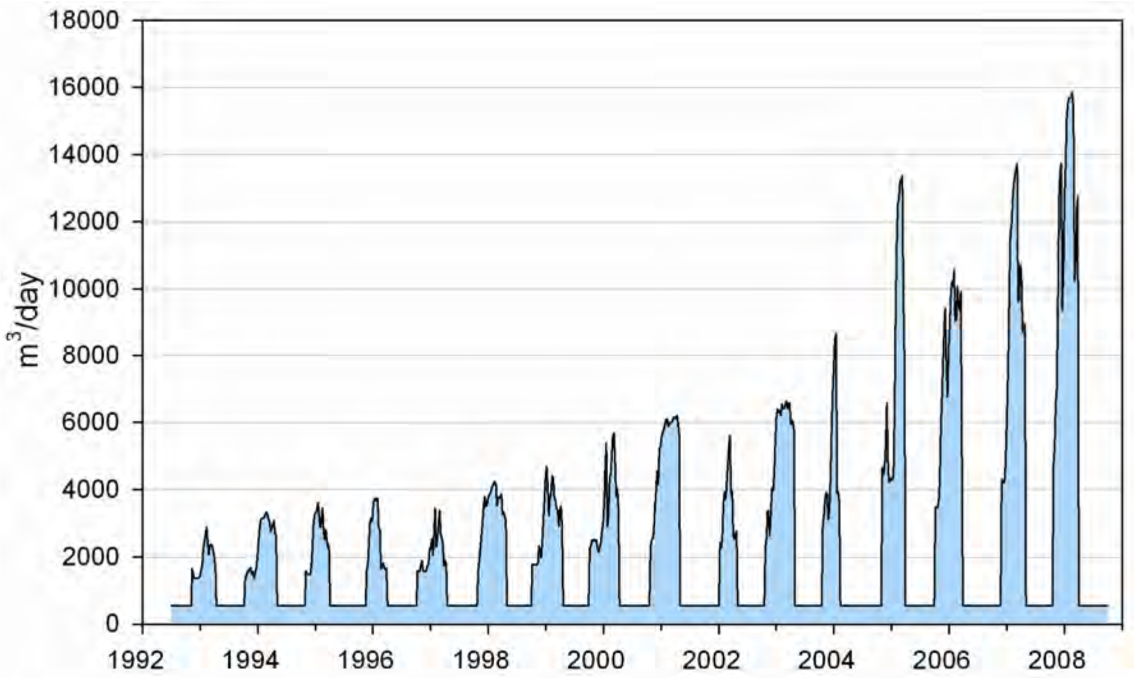

Figure D5: Simulated abstraction in the Te Ore Ore water management zone between 1992 and 2008

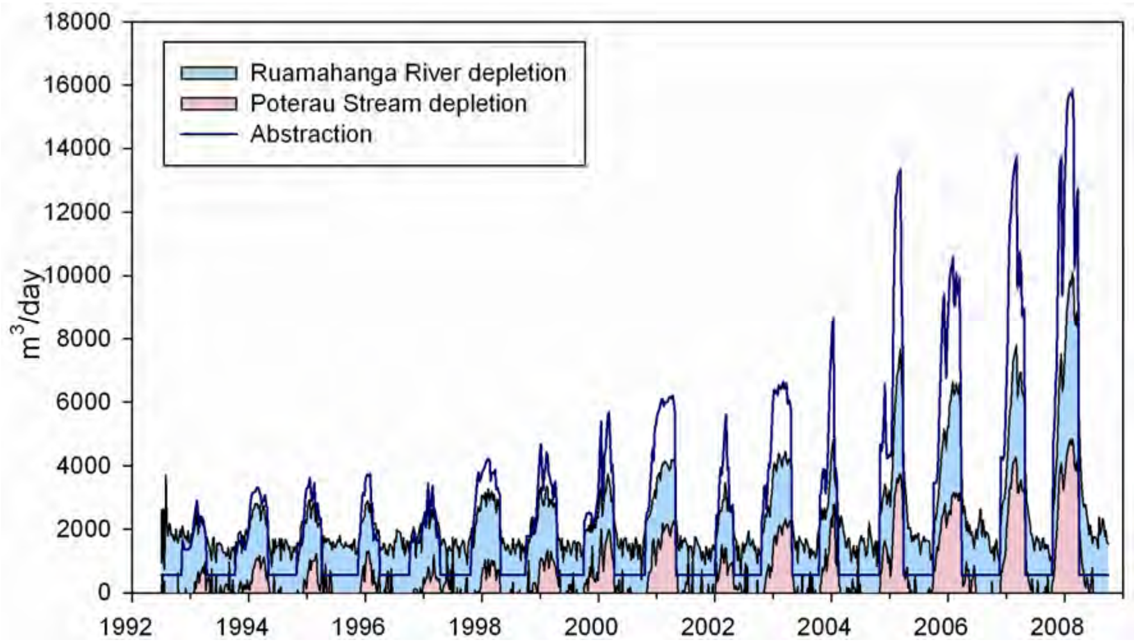

Figure D6: Simulated total surface water depletion resulting from abstraction in the Te Ore Ore zone from all consented bores between 1992 and 2008. Groundwater abstraction in adjacent water management zones is responsible for depletion apparently exceeding pumping rate during winter.

D.4.8 Drawdowns

Figure D7 shows the modelled drawdown during the last irrigation season (2007/08) of the transient 1992–2008 simulation. Figure D5 shows that modelled abstraction during this period was about 16,000 m^3/day from the zone. The modelled drawdown in the central part of the basin reaches approximately 6 m (larger near individual pumping wells) with significant drawdown extending across a majority of the Te Ore Ore basin.

The simulation is consistent with groundwater level monitoring data (Figure D8); the figure also shows a long-term decline in groundwater levels most likely attributable to the increased volume of groundwater abstraction in recent years.

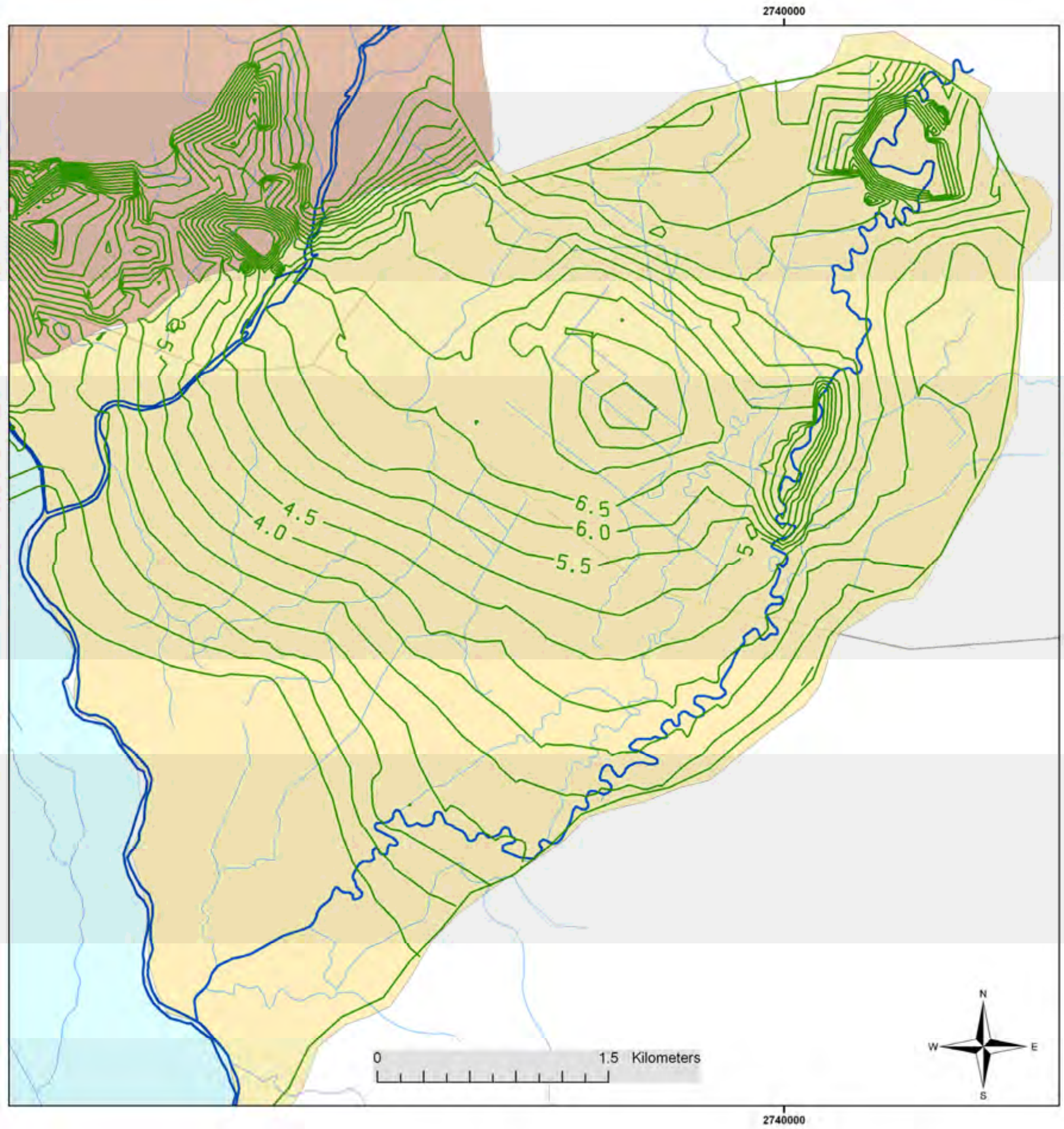

Figure D7: Modelled drawdown in the Te Ore Ore basin, February 2008. Contour lines are at 0.5 m intervals

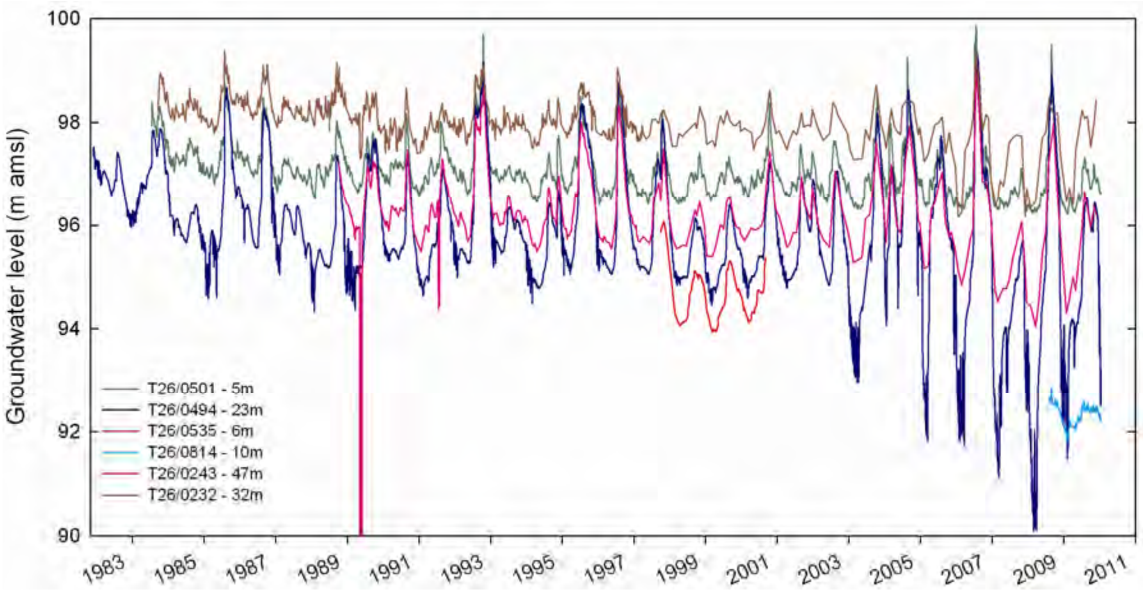

Figure D8: Temporal groundwater levels (m) observed in the Te Ore Ore water management zone between 1983 and 2010

D.4.9 Abstraction scenarios

The transient flow model for the Upper Valley catchment was used to simulate a number of abstraction scenarios to further characterise the relationship between groundwater abstraction from different parts of the Te Ore Ore water management zone and surface water depletion. For some of these scenarios, the transient run time was shortened to eight years (14 June 2000 to 1 October 2008 <u>or</u> model days 2,908 to 5,936).

The following scenarios were simulated:

Scenario 1: Abstraction from consented bores located in the Te Ore Ore zone's higher permeability area to the west of the Poterau Stream. Bores range in depth from very shallow (<10 m) to about 30 m (bores on model slices 2 and 3; see Gyoparia and McAlister 2010a for details). No other abstraction in the Upper Valley catchment is occurring in this scenario. The overall objective of this scenario is to quantify the likely magnitude and characteristics of surface water depletion effects associated with abstraction from unconfined and semi-confined aquifers in the higher permeability western portion of the Te Ore Ore basin.

Scenario 2: This scenario is similar to Scenario 1 but only modelled abstraction from consented bores on model slice 2 (7 to 10 m deep). This scenario is intended to characterise the degree of surface connectivity associated with the shallow unconfined aquifer west of the Poterau Stream (i.e. Category A takes only).

Scenario 3: Abstraction from consented bores in the Te Ore Ore zone located to the east of the Poterau Stream to a depth of about 40 m (bores on model slices 2 and 3). No other abstraction in the Upper Valley catchment is taking place during this scenario. The scenario is intended to indicate the likely nature of surface water depletion effects associated with abstraction from the eastern (lower permeability) section of the Te Ore Ore basin.

Figure D9 shows the results of Scenario 1 in terms of surface water depletion effects when pumping only occurs west of the Poterau Stream. The figure indicates the total depletion effect is about 80 to 85% of the pumping rate (i.e. a depletion factor of between 0.8 to 0.85) – with depletion of the Ruamahanga River accounting for approximately 60% of the total depletion effect. Therefore, virtually all the abstraction is derived from surface water depletion when pumping occurs from unconfined and semi-confined aquifers.

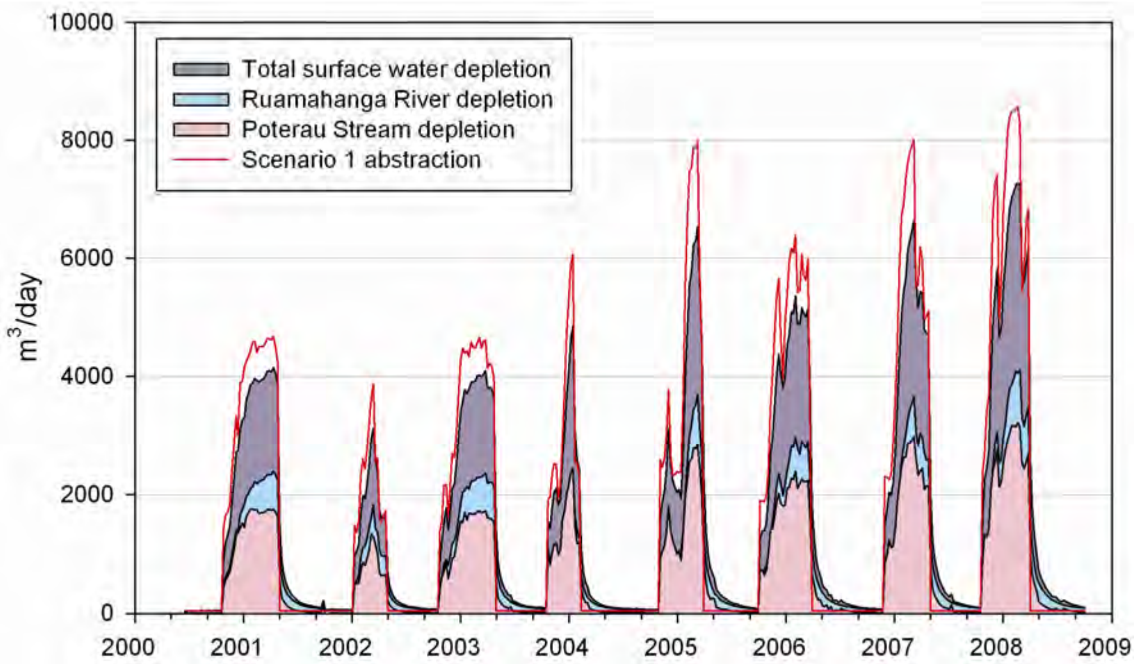

Figure D9: Scenario 1 model results for the period 2000 to 2008 – surface water depletion when pumping from Category A area only of the Te Ore Ore zone. Pumping from model slices 2 and 3 (ground surface to about 30 m depth).

In Scenario 2, when pumping is restricted to bores drawing from the shallow, near surface unconfined aquifer to the west of the Poterau Stream, the depletion effect increases to approximately 90% of the abstraction rate at the end of the pumping season (Figure D10). The results of this scenario indicate depletion is likely to occur equally from the Ruamahanga River and the Poterau Stream.

The results of Scenario 3 (Figure D11) demonstrate the stream depletion response to abstraction from the eastern side of the Te Ore Ore zone. There is clearly still a high degree of connectivity between the aquifers in this area and the Ruamahanga River and Poterau Stream. However, the depletion effect is more attenuated than in the Category A (western) part of the Te Ore Ore plain. The model predicts that the depletion effect by the end of an irrigation season is 70 to 80% of the abstraction rate. The depletion factor (q/Q) is about 0.5 for the Ruamahanga River, and about 0.3 for the Poterau Stream.

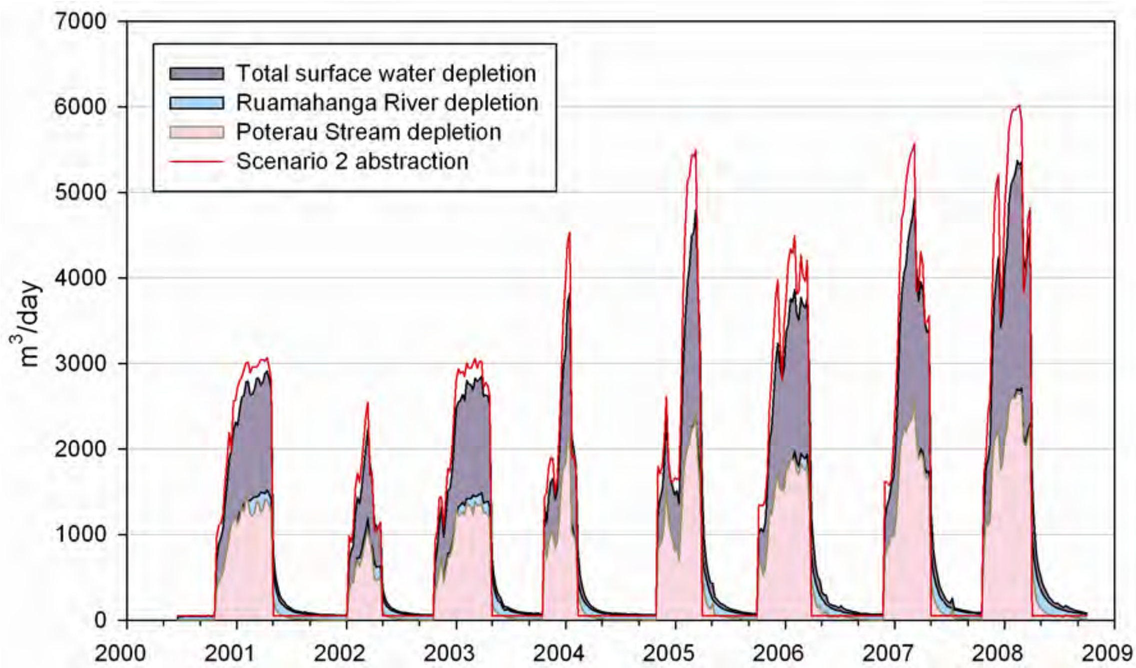

Figure D10: Scenario 2 model results for the period 2000 to 2008 – surface water depletion when pumping from Category A area only of the Te Ore Ore zone. Pumping from model slice 2 (top 10 m depth).

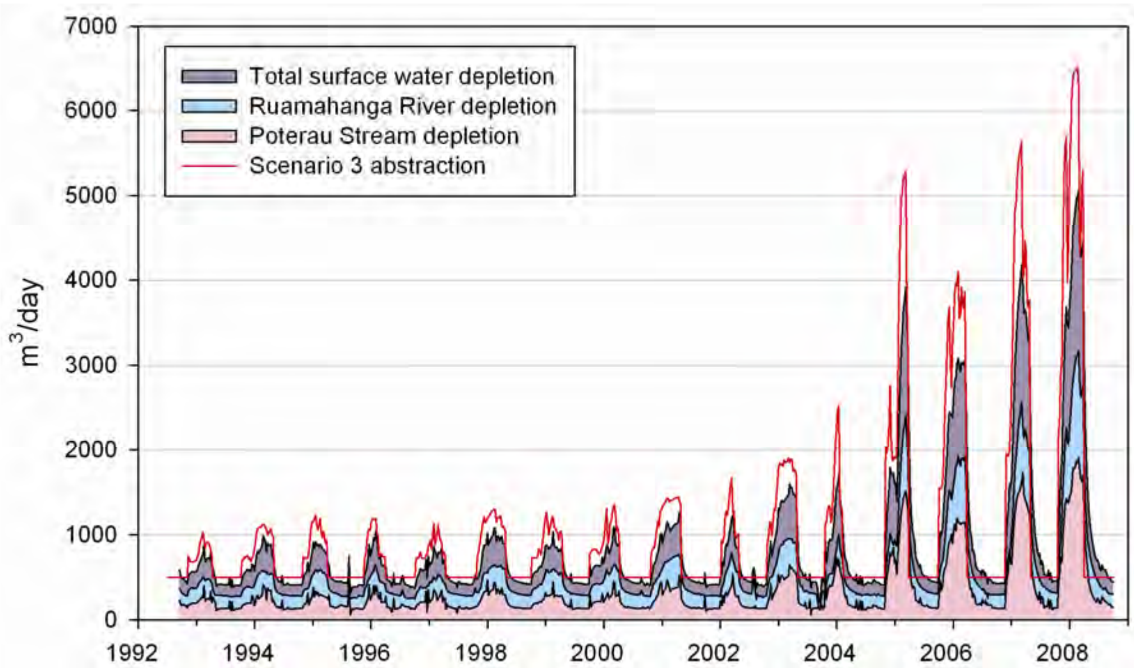

Figure D11: Scenario 3 model results for the period 1992 to 2008 – surface water depletion when pumping from the eastern side of the Te Ore Ore zone. Pumping from model slices 2–4 (ground surface to about 45 m depth)

Scenarios 1 and 2 demonstrate that surface water and groundwater in the western part of the Te Ore Ore zone are dynamically connected. Surface water-groundwater fluxes appear to be highly sensitive to groundwater abstraction and respond virtually instantaneously even to pumping from the semi-confined aquifers. Based on this assessment it is recommended that this area should therefore be assigned to the Category A hydraulic connectivity zone to a depth of 30 m. Scenario 3 shows that the aquifer system on the eastern side of the Te Ore Ore basin also exhibits significant connectivity with surface water but has a longer lag time than occurs in response to abstraction from the western (Category A) area. It is therefore recommended this area should be classified as a Category B hydraulic connectivity zone.

D.4.10 Groundwater management options for the Te Ore Ore water management zone

Groundwater-surface water interaction zones

- Due to the very high degree of connectivity between the aquifers (unconfined and semi-confined) and the surface water environment, the western part of the Te Ore Ore water management zone (west of the Poterau Stream) should be classified as Category A (direct hydraulic connection) to a depth of 30 m.

- Modelling indicates that abstraction on the eastern side of the Te Ore Ore water management zone results in a smaller surface water depletion with increased lag time compared to abstraction closer to the Ruamahanga River. It is therefore recommended that this area be classified as Category B (high hydraulic connectivity). The total depletion factor (q/Q) for this section of the Te Ore Ore water management zone should be 0.8, attributable to both depletion of the Ruamahanga River and the Poterau Stream.

- Category B classification should be applied to all takes deeper than 30m across the entire Te Ore Ore basin and all takes east of the Poterau Stream.

Groundwater allocation (Category B)

- Aquifers in the Te Ore Ore zone should be managed as a single groundwater system. Model simulations show that the deeper semi-confined aquifers exhibit a significant inter-connection with the surface environment over relatively short pumping durations.

- Groundwater allocation should be primarily calculated using the 7-day MALF for the Ruamahanga River at Wardell's bridge as a reference for surface water depletion effects. This is 3,072 L/s (265,420 m^3/day).

- Because of the large inter-annual range in rainfall recharge, allocation should be referenced to the lower quartile annual rainfall recharge to protect the resource during successive dry years. This is 1.8 x 10^6 m^3/year ('reference LSR') calculated for the period 1992 to 2008. It is recommended that allocation does not exceed about 20-30% of the reference LSR..

- Allocation should also be referenced to the depletion effect on the Poterau Stream which, in the absence of adequate monitoring data, is assumed to have a natural summer mean low flow of 100 L/s (derived from the numerical model).

- Adoption of a depletion factor of 0.5 for the Ruamahanga River and 0.3 for the Poterau Stream will reflect the proportions of the total depletion associated each system (total effect is calculated to be q/Q = 0.8).Annual allocation should be based on a pumping duration of 180 days.

Table D3 provides allocation options for the Te Ore Ore water management zone based upon the depletion effects on the Ruamahanga River and the Poterau Stream and referenced to land surface recharge. Current (2010) abstraction from Category B takes is estimated to be approximately 7,000 m3/day (26% of total zone allocation), of which 20% would be assigned to groundwater allocation and the balance to surface water allocation (a surface water depletion factor, q/Q, of 0.8 is recommended for Category B).

Option 1 in Table D3 is recommended as the effects on the Poterau Stream are a primary consideration given the current degraded condition of this waterway. This option corresponds to approximately 30% of the reference LSR. This option would also limit drawdowns to within present magnitudes.

Table D3: Groundwater allocation options for the Te Ore Ore water management zone

Option	Cumulative depletion effect on Ruamahanga River	Depletion (m^3/day)	Groundwater allocation at q/Q = 0.5 x [Ruam] (m^3/day)	Allocation (m^3/year x 10^6)	% of reference LSR*	Est. % effect on Poterau Stream**
1	0.5 % MALF	1,330	2,660	0.48	27	9
2	1% MALF	2,600	5,200	0.94	52	18
3	1.5% MALF	4,000	8,000	1.44	80	28

* Reference LSR – lower quartile annual land surface (rainfall) recharge for the period 1992 to 2008.

** Poterau Stream natural mean low flow is estimated to be 100 L/s (8,640m^3/day). The depletion factor for the stream is 0.3.

D.5 Waingawa water management zone

D.5.1 Overview

Delineation: The Waingawa water management zone is defined by the alluvial fan area between the Waingawa and Waipoua rivers, extending from the Tararua foothills to the Ruamahanga River (Figure D12). The Masterton Fault cuts through the centre of the zone and is associated with the spring discharge zone around Masterton.

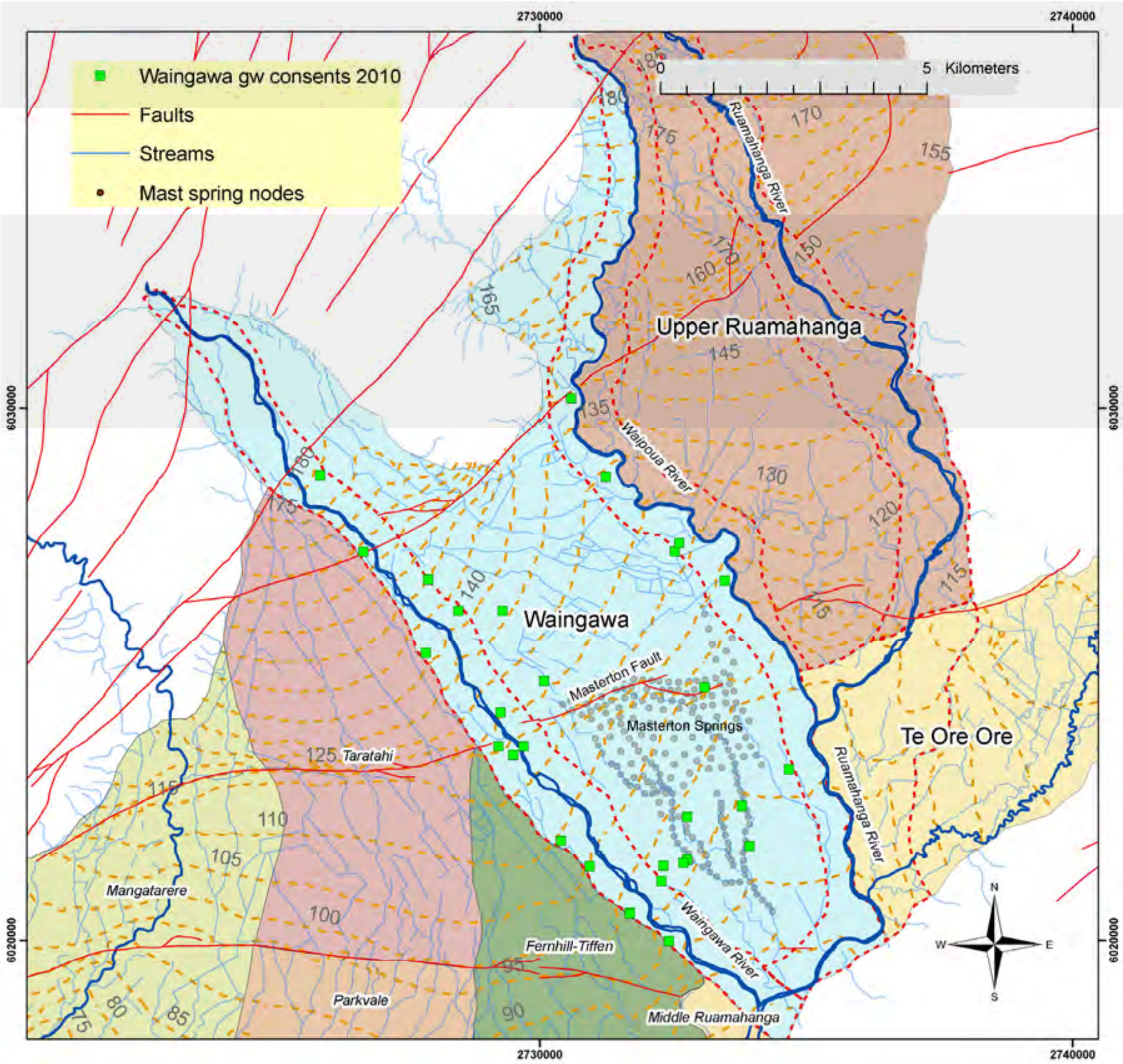

Figure D12: The Waingawa water management zone map showing existing groundwater bores with consented abstraction (green squares) and simulated groundwater flow contours (brown dashed lines at 5 m intervals in metres above mean sea level). The extent of the groundwater system classified as Category A (direct hydraulic connection) is illustrated by the red dashed lines which either follow the edge of mapped Q1 alluvium or represent a 500 m buffer from the river centre line. Model spring nodes in the Masterton area are also shown (grey circles).

Area: 77.7 km^2.

Boundaries: The western boundary is coincident with the recent terrace edge of the Waingawa River which forms a groundwater divide between the Upper and Middle Valley catchments.

The eastern boundary follows the Waipoua River and the Ruamahanga River which form internal hydraulic boundaries within the Upper Valley catchment.

The northern boundary follows the mapped edge of late Quaternary alluvium at the base of the Tararua foothills. The southern boundary similarly follows the edge of the catchment boundary with the Tertiary sequence of the eastern hills. The Ruamahanga River also follows this boundary.

Principal surface water systems: Waingawa River, Waipoua River, Ruamahanga River, Masterton springs.

Aquifer sequences: Single heterogeneous alluvial fan unconfined to semi-confined leaky aquifer system.

Recharge: Average annual recharge is x 18.3 $x10^6$ m^3.

Existing RFP zones: Upper Plain, Masterton (Te Ore Ore western edge). The current allocation status of each of these zones is shown in Table D4.

Table D4: 'Safe yield' estimates and allocation for the existing RFP (WRC 1999) groundwater zones located in the Waingawa water management zone

Existing RFP zone	RFP 'safe yield' (m^3/year)	Current allocation (m^3/day)	% allocated
Upper Plain	17×10^6	30,200	21
Masterton	5.5×10^6	4,300	10

D.5.2 Current abstraction from the Waingawa water management zone

As at June 2010, there were a total of 32 consented groundwater takes in the Waingawa water management zone. The locations of these abstractions are shown on Figure D12. The total consented abstraction from the zone stands at about 34,000 m^3/day which is mostly taken from shallow bores screened in alluvium in close proximity to the Waingawa River Q1. The total consented abstraction outside the areas mapped as Category A on Figure D12 is 6,300 m^3/day and therefore over 80% of the abstraction in this zone occurs from Category A (predominantly the Waingawa River Category A).

D.5.3 Hydrogeology summary

The Waingawa, Waipoua and Ruamahanga rivers are associated with an extensive coalescing fluvio-glacial fan system. These fan deposits dominate the Waingawa zone and comprise poorly sorted matrix-rich gravels, silts and sands. The sequence is very heterogeneous, behaving essentially as a single hydraulic unit and generally possessing a low bulk hydraulic conductivity capable of sustaining only low to moderate bore yields. However, localised sediment reworking occasionally facilitates higher yields. The shallow fan deposits north of the Masterton Fault appear to be the product of the Waingawa River which has historically flowed an eastward course towards the Waipoua River, and southwards through the Masterton springs area. As a consequence, the shallow deposits in this area are regarded to exhibit a higher hydraulic conductivity (than deeper deposits) due to sediment reworking.

The fan sequence is traversed by the Masterton and Mokonui faults – these faults are associated with intense structural deformation across the northern portion of the Wairarapa basin which has created a series of shallow sub-basins (synclines) between the faults. The aquifer sequence is uplifted and thins on the up-gradient side of the faults causing groundwater to discharge in the vicinity of the faults – particularly along the Masterton Fault.

Shallow high-transmissivity reworked gravels of Q1 age occur along the modern day channels and floodplains of the Waingawa, Waipoua and Ruamahanga rivers to a depth of 10-15 m. These deposits are distinct from the low-yielding Q2+ fan alluvium and are generally highly productive aquifers which are directly connected to the rivers. Within the Waingawa zone, the Q1 alluvium deposited by the Waingawa River is a particularly productive aquifer from which over 80% of the zone abstraction currently occurs.

The general groundwater flow pattern in the Waingawa zone reflects the regional topography. Groundwater flows south-easterly off the fan deposits and away from the (losing) Waingawa River towards the lower reaches of the Waipoua and Ruamahanga rivers. The shape of the groundwater flow contours (Figure D12) and gauging data indicate that the Waipoua River receives inflow from groundwater above the Masterton Fault (i.e. it is a ‘gaining’ river). Conversely, the Waingawa River discharges to groundwater over the majority of its length.

Rainfall infiltration is an important groundwater recharge source in the Upper Valley catchment in addition to river bed leakage. The main influence on the spatial variability of recharge is the steep rainfall gradient across the valley from 1,200 to 1,300 mm/year against the Tararua Range to 600 to 700 mm/year at the eastern hills.

D.5.4 Hydrology

Three significant river systems bound the Waingawa zone: the Waingawa, Waipoua and Ruamahanga rivers.

The Waingawa River is a tributary of the Ruamahanga River and has an estimated 7-day MALF of 1.72 m^3/s at the Ruamahanga confluence. On the plains, a number of faults cut across the river channel and tectonic activity appears to frequently displace the river course. It is evident from prominent channel patterns observed on LIDAR imagery that the river has migrated through the Masterton area and probably merged with the Waipoua River since the last glaciation.

The Waipoua River is the first major tributary entering the Ruamahanga River from the Tararua Range along the western margin of the Wairarapa Valley. This river has an estimated 7-day MALF of 0.49 m^3/s at the Ruamahanga River confluence. During periods of low flow the Waipoua River exhibits a complex pattern of losses and gains along its course which seems to reflect the influence of major faults on the thickness of alluvial sediments. In particular, the river exhibits appreciable flow gains upstream of the Masterton Fault.

The Ruamahanga River follows the south-eastern edges of the zone. The river has a mean flow of about 24 m^3/s at the Wardell's bridge gauge site and a 7-day MALF of 3.07 m^3/s.

The Masterton springs comprise an extensive channel network occupying the area between the Masterton Fault, Ruamahanga River and Waingawa River (Figure D12). Many of the springs emerge around the Masterton Fault which impedes throughflow of groundwater through the alluvial sediments. The total discharge from the Masterton springs is of the order of 0.15 to 0.20 m^3/s with the numerical groundwater model predicting a summer spring baseflow of about 0.30 m^3/s.

D.5.5 Zone management objective

The principal management objective for groundwater allocation in the Waingawa zone is to ensure the sustainable use of groundwater resources while protecting the instream values of hydraulically connected surface water ecosystems.

Within the Waingawa zone, the Waingawa, Waipoua and Ruamahanga rivers and the spring-fed Masterton streams all have a direct connection to the groundwater environment and the protection of baseflow in these systems is of primary importance.

D.5.6 Numerical modelling

Baseline (no-abstraction) water balance

The numerical groundwater flow model was used to quantify the natural water balance for the Waingawa zone by running the model for a period of 16 years (1992 to 2008) with no abstraction. This scenario provides a baseline simulation against which the effects of abstraction can be evaluated. Of particular relevance to assessing the sustainability of abstraction, the model provides quantification of the cumulative depletion effects of groundwater pumping on the surface water environment.

The principal water balance components for the Waingawa zone are rainfall recharge and groundwater-surface water fluxes. Figure D13 shows the modelled annual rainfall recharge for the Waingawa zone for the period 1992 to 2008 which suggests an annual average recharge of 18.3 x 10^6 m^3. The lower quartile annual recharge for this dataset is 12.4 x 10^6 m^3/year.

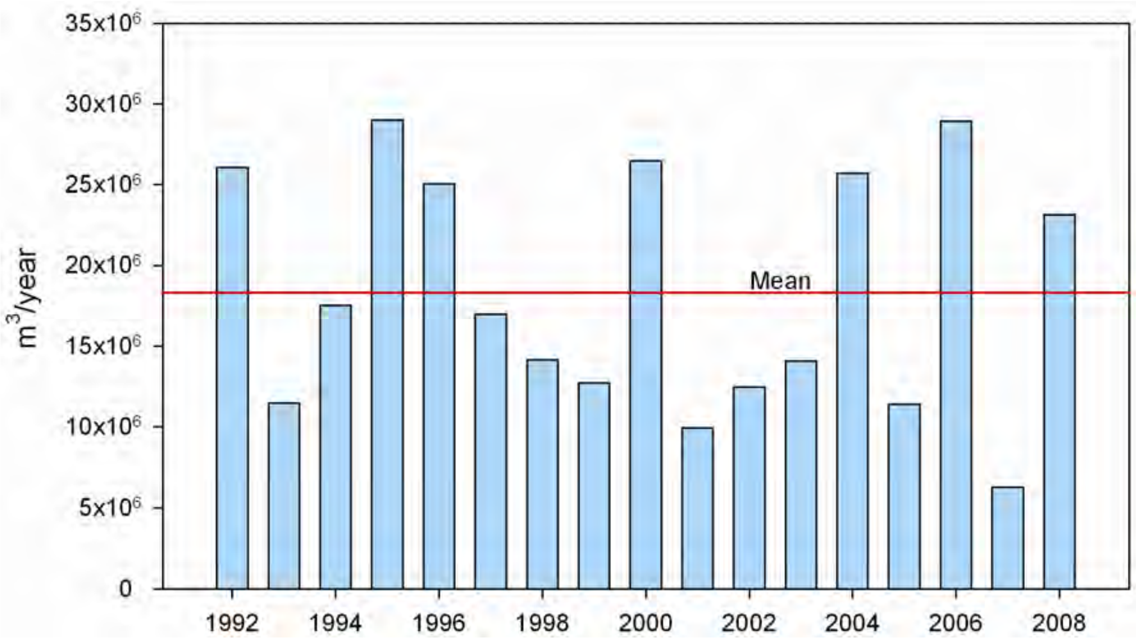

Figure D13: Modelled annual rainfall recharge 1992–2008 for the Waingawa zone in the Upper Valley catchment

The simulated natural fluxes (in the absence of groundwater abstraction) between surface water and groundwater within the Waingawa zone are shown in Figure D14. Positive fluxes shown on the plot represent flows from surface water to groundwater (i.e. ‘losing’ rivers), and negative fluxes represent flow from groundwater to surface water (i.e. ‘gaining’ systems). The distinct characteristic of the Waingawa River as a ‘losing’ river is shown – the flux into the aquifer is highest in summer when the hydraulic gradient between the river and the water table is most pronounced.

Figure D14 also shows that the other three surface water systems (Waipoua River, Ruamahanga River and Masterton springs) all have a similar net minimum baseflow contribution from groundwater of between 20,000 to 30,000 m^3/day during summer. Winter baseflows are three to four times higher than the summer flux.

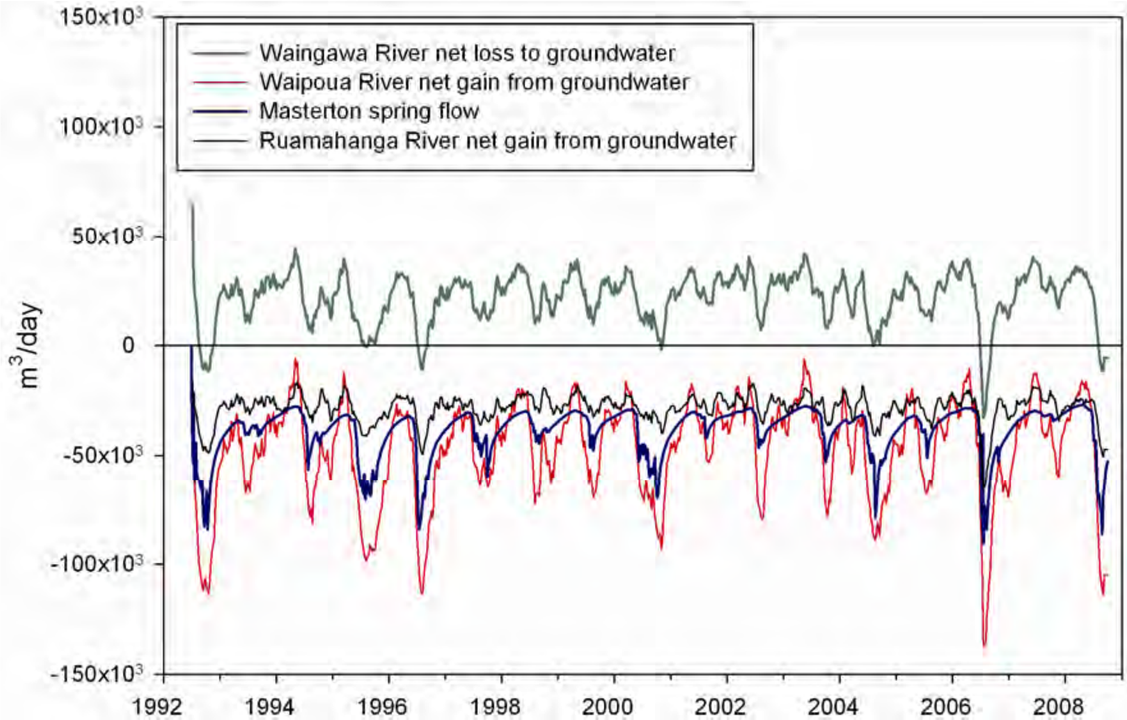

Figure D14: Simulated net natural fluxes in the Waingawa zone when no groundwater abstraction is occurring. Positive fluxes represent flows from surface water to groundwater (i.e. 'losing' rivers), and negative fluxes represent flow from groundwater to surface water (i.e. 'gaining' rivers).

D.5.7 Pumping simulation

The transient groundwater flow model for the Upper Valley catchment was used to simulate abstraction scenarios to characterise the relationship between groundwater abstraction from different parts of the zone and potential surface water depletion effects. This work focused upon the effects of groundwater abstraction outside the delineated Category A boundaries to evaluate a sustainable groundwater allocation limit for this area (since abstraction from Category A areas will be managed under the surface water allocation regime).

Since most of the current abstraction in this zone occurs from areas classified as Category A and only a relatively small quantity of groundwater is currently abstracted from the central part of the Waingawa zone, a synthetic pumping simulation was formulated. This entailed retaining current abstraction bores outside the Category A area and adding 35 bores distributed evenly across the zone (excluding Category A areas). The additional bores each have a peak seasonal pumping rate of 180 m^3/day and duplicate the pumping record for bore T26/0238 (pow ID 2061). Figure D15 shows the bore array which was placed on model slice 3 (15 to 20 m deep). The distributed nature of the bore array will result in a generalised or hypothetical effect on surface water.

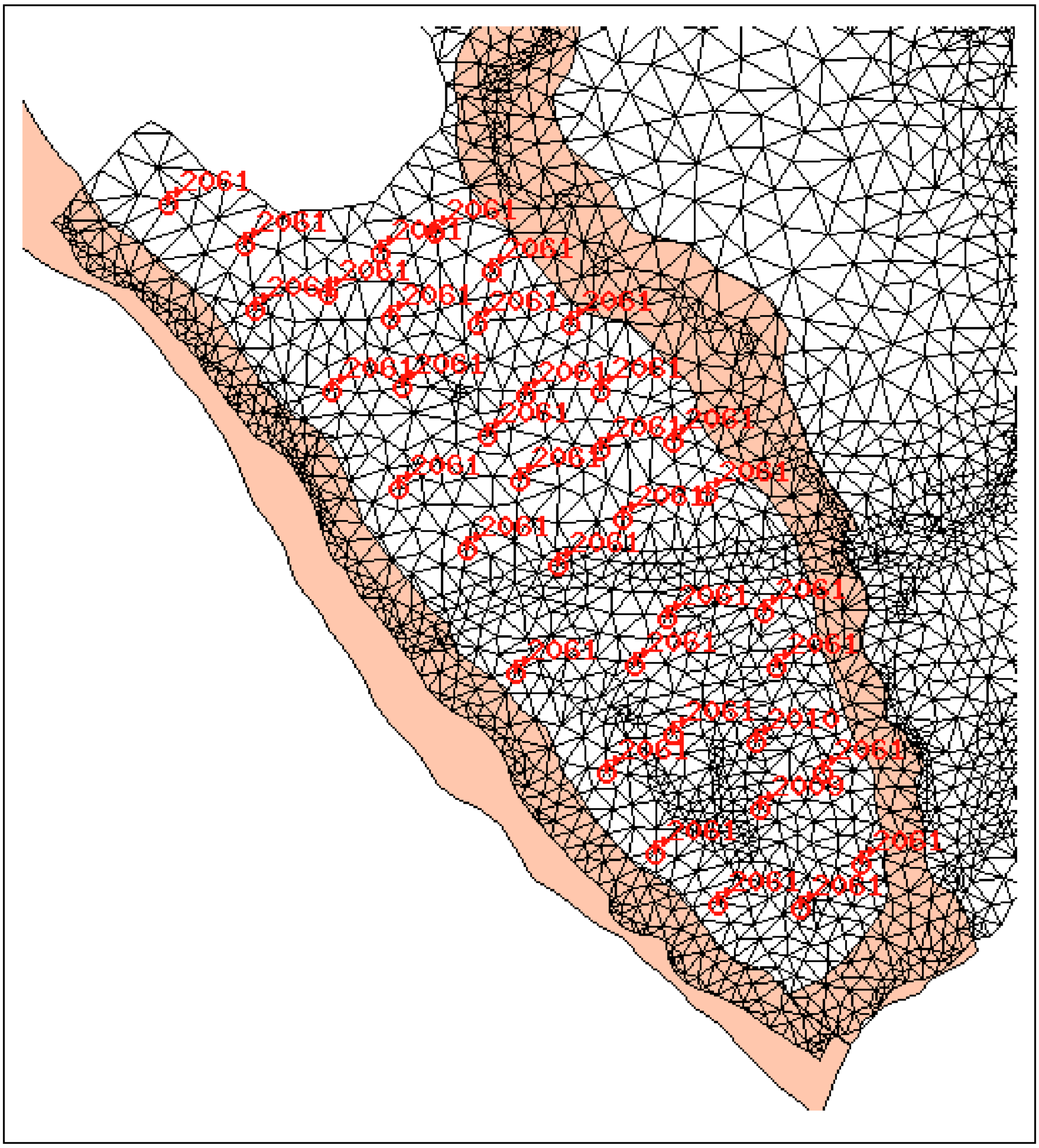

Figure D15: Synthetic bore array used for the investigation of groundwater abstraction effects on the surface water environment in the Waingawa zone. Bores located on model slice 3 (15 to 20 m depth). The shaded area represents the extent of the proposed Category A classification.

Figure D16 shows the results of the pumping scenario in terms of surface water depletion effects. The combined seasonal surface water depletion effect averages 60% of the pumping rate over the 16 year simulation, ranging from 50 to 70% of cumulative pumping over this period. The adoption of a representative combined surface water depletion factor of 0.6 is therefore considered appropriate for this zone.

Figure D16 also provides a breakdown of the total simulated depletion effect in terms of the individual surface water systems. The Masterton springs are the most sensitive to abstraction and experience a modelled peak seasonal depletion of about 2,000 m^3/day (23 L/s). This depletion is caused by a combination of reduced throughflow from the north across the Masterton Fault and direct depletion effects from bores located close to spring channels. The Waipoua and Waingawa rivers each experience similar depletion effects (in the order of 1,000 m^3/day and about 12 to 15% of the total pumping rate). The least sensitive system is the Ruamahanga River with the increase in depletion from 2006 onwards representing the development of a single high-yielding abstraction bore near to the river at this time (near the Category A boundary). Ultimately, however, the total depletion effect will be experienced by the Ruamahanga River downstream of the Waingawa confluence since all the surface water systems in this zone are tributaries of the Ruamahanga River.

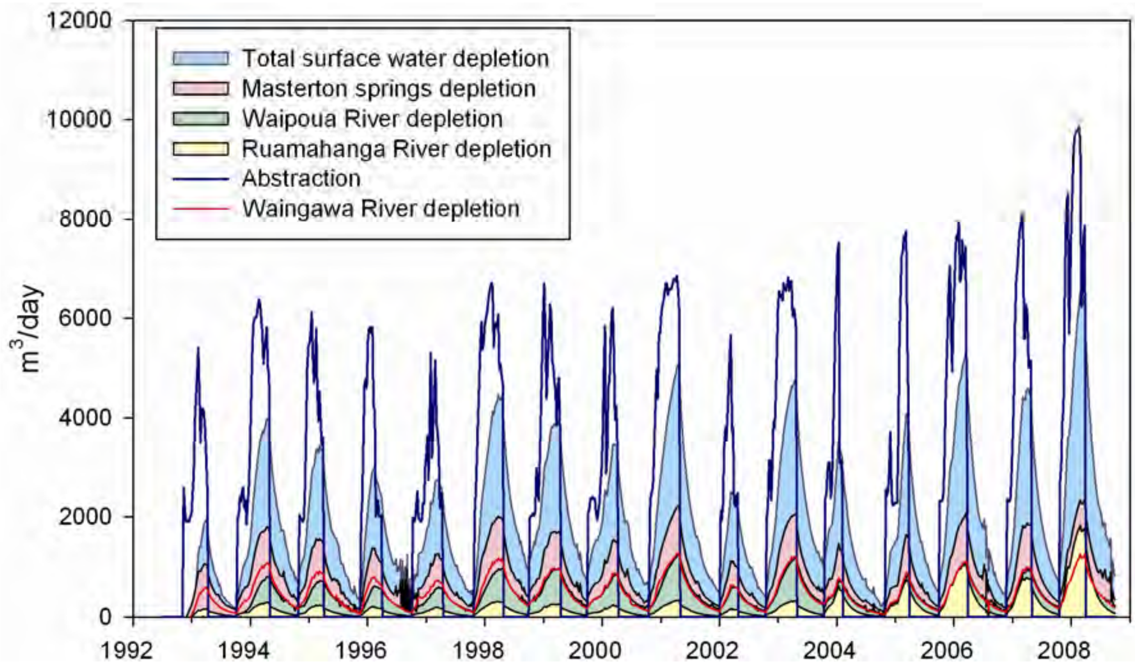

Figure D16: Simulated surface depletion effects resulting from pumping from a distributed bore array in the Waingawa zone outside Category A

D.5.8 Groundwater management options for the Waingawa water management zone

Groundwater-surface water interaction zones

- The mapped Q1 alluvium associated with the main river systems (Waingawa, Waipoua and Ruamahanga) should be classified as Category A. Where the recent alluvium is not mapped with confidence or is very narrow, a 500 m buffer should be used to define the zone boundary from the river centre-line (this distance is based on analytical and numerical modelling). The spatial extent of the proposed Category A classification is shown on Figure D12.

- The Category A classification should extend to a depth of 20 m.

- Category B classification should be applied to the Masterton springs area between the Ruamahanga and Waingawa rivers. A Category B buffer should also be placed between Category A and Category C elsewhere in the Waingawa water management zone.

- Category B should extend to 20 m depth.

- The area north of the Masterton Fault should be classified as Category C to reflect the relatively indirect hydraulic connection to surface water in this area.

Groundwater allocation

- Heterogeneous fan deposits in the Waingawa zone should be managed as a single groundwater system. Groundwater model simulations show that the deeper semi-confined aquifers exhibit a significant connection to the surface water environment over relatively short pumping durations.

- Groundwater allocation should be primarily referenced to a depletion effect on the combined mean annual low flow for the Waingawa River, Waipoua River and Masterton springs. This is estimated to be 2.41 m^3/s (208,000 m^3/day).

- The average surface water depletion factor for groundwater abstraction in the Waingawa zone (for Category B and C groundwater takes) is 0.6.

- The combined depletion effects on the three surface water systems will approximate the depletion experienced by the Ruamahanga River downstream of the Waingawa confluence (in addition to the depletion associated with groundwater abstraction from the Te Ore Ore and Upper Ruamahanga zones).

- Allocation should also be referenced to the lower quartile annual rainfall recharge calculated from the period 1992 to 2008 to protect the resource from successive dry years. This is 12.4 x 10^6 m^3/year ('reference LSR'). As a rule of thumb, it is recommended that allocation does not exceed about 20-30% of the reference LSR.

- Annual allocation should be based on a pumping duration of 180 days.

Table D5 provides allocation options for the Waingawa water management zone. Current (2010) abstraction from areas classified as Category B and Category C is estimated to be approximately 6,300m^3/day, of which only 40% would be assigned to groundwater allocation in the Category B areas (assuming a surface water depletion factor, q/Q, of 0.6), and 100% in the Category C area.

Option 2 in Table D5 is recommended. This corresponds to 15% of the reference LSR and a depletion effect equivalent to 2.4% of MALF in the Ruamahanga River. The depletion effects of groundwater abstraction from the other two Upper Valley water management zones (Te Ore Ore and Upper Ruamahanga) will also contribute to the total flow depletion effect on the Ruamahanga River.

Table D5: Groundwater allocation options for the Waingawa water management zone

Option	Cumulative depletion effect on Waingawa, Waipoua Rivers and Masterton springs low flow	Depletion (m^3/day)	Groundwater allocation using q/Q = 0.6 (m^3/day)	Allocation x 10^6 (m^3/year)	% of reference LSR*
1	2%	4,160	7,000	1.3	10
2	3%	6,240	10,400	1.9	15
3	4%	8,320	14,000	2.5	20
4	5%	10,400	17,300	3.12	25

* Reference LSR – lower quartile annual land surface (rainfall) recharge for the period 1992 to 2008.

** The 7-day MALF for the Ruamahanga River at Wardell's bridge is 3,027 L/s (261,500 m^3/day).

D.6 Upper Ruamahanga water management zone

D.6.1 Overview

Delineation: The proposed Upper Ruamahanga water management zone covers the alluvial fan area to the east of the Waipoua River and north of the Masterton Fault (Figure D17) and contains contains the upper reaches of the Ruamahanga River and a tributary, the Kopuaranga River. The Mokonui Fault cuts through the centre of the zone. The zone generally has poor groundwater resource potential except close to the main river systems where aquifers comprising

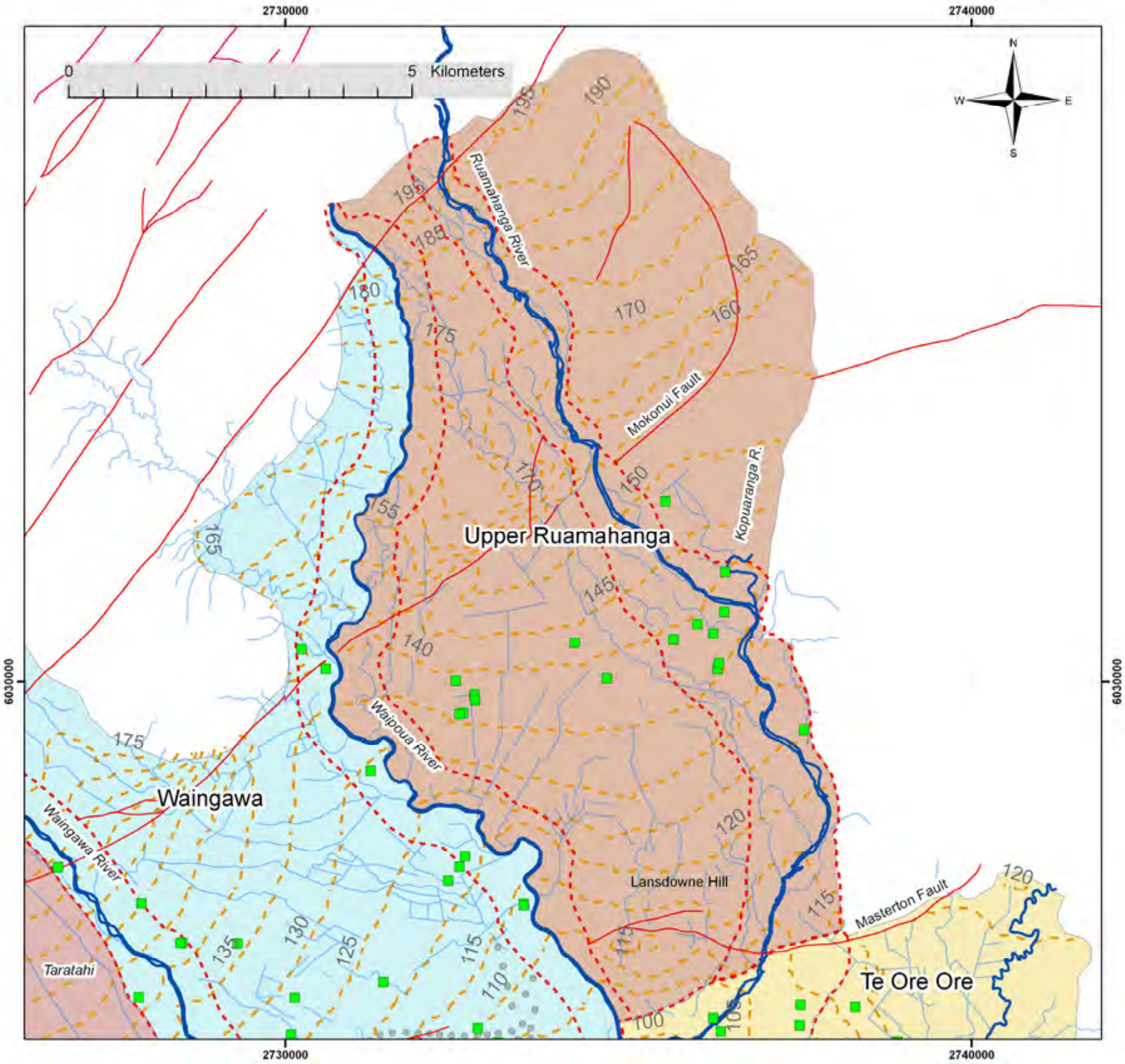

Figure D17: The proposed Upper Ruamahanga water management zone map showing existing groundwater bores with consented abstraction (green squares) and simulated groundwater flow contours (brown dashed lines at 5 m intervals in metres above mean sea level). The extent of the groundwater system classified as Category A (direct hydraulic connection) is illustrated by the dashed red lines which either follow the edge of mapped Q1 alluvium or represent a 500 m buffer from the river centre line. Active faults are shown as solid red lines.

shallow recent alluvium sustain higher bore yields. These aquifers exhibit a high degree of connectivity to the surface water environment.

Area: 72 km^2.

Boundaries: The western boundary follows the centre-line of the Waipoua River which is inferred to represent a hydraulic boundary within the Upper Valley catchment.

The eastern and northern boundaries mark the limit of late Quaternary alluvium at the base of the Tararua foothills and eastern hills.

The southern boundary is coincident with the Masterton Fault and marks the boundary between this zone and the geologically distinct Te Ore Ore basin.

Principal surface water systems: Waipoua River, Ruamahanga River, Kopuaranga River as well as numerous spring-fed channels between the Waipoua and Ruamahanga rivers including the Waipipi Stream.

Aquifer sequences: Single heterogeneous alluvial fan unconfined to semi-confined leaky aquifer system.

Recharge: Average annual recharge is 23.5 x 10^6 m^3.

Existing RFP zones: Opaki, Upper Opaki, Rathkeale. The current allocation status of each of these zones is shown in Table D6.

Table D6: 'Safe yield' estimates and allocation for the existing RFP (WRC 1999) groundwater zones located in the proposed Upper Ruamahanga water management zone

Existing RFP zone	RFP 'safe yield' (m^3/year)	Current allocation (m^3/day)	% allocated
Opaki	2.3 x 10^6	555	3
Upper Opaki	4.5 x 10^6	864	5
Rathkeale	3.0 x 10^6	10,100	80

D.6.2 Current abstraction from the Upper Ruamahanga water management zone

Figure D17 shows the location of the 13 existing consented groundwater takes in the proposed Upper Ruamahanga water management zone. The total consented abstraction from the zone totals approximately 11,500 m^3/day which is mostly taken from a cluster of bores in the Q1 alluvium of the Ruamahanga River near the Kopuaranga River confluence (existing Rathkeale zone). The total consented abstraction outside Category A is only 550 m^3/day reflecting the generally poor groundwater resource potential in the older Quaternary gravels away from the riparian margins of the main river systems.

D.6.3 Hydrogeology summary

The Waipoua and Ruamahanga rivers are associated with an extensive coalescing fluvio-glacial fan system. The fan deposits dominate the Upper Ruamahanga zone and comprise poorly sorted matrix-rich gravels, silts and sands. The sequence is very heterogeneous, behaving essentially as a single hydraulic unit and generally possessing a low bulk hydraulic conductivity capable of sustaining only low to moderate bore yields. The fan sequence is disrupted by the Masterton and Mokonui faults – these major structures are associated with intense structural deformation which has created a series of shallow sub-basins (synclines) between the faults and produced uplifted cores of older sediments to form Lansdowne and Tirohanga hills. The fan sequence generally thins on the up-gradient side of the faults causing groundwater to discharge in the vicinity of the faults – particularly along the Masterton Fault.

Shallow high-transmissivity reworked gravels of Q1 age occur along the modern day channels and floodplains of the Waipoua and Ruamahanga rivers to a depth of 10-15 m. These deposits are distinct from the low-yielding Q2+ fan alluvium and are generally highly productive aquifers which are directly connected to the rivers. Within the Upper Ruamahanga zone, the Q1 alluvium deposited by the Ruamahanga River forms a particularly productive zone from which a majority of abstraction currently occurs.

The general groundwater flow pattern in the Upper Ruamahanga zone reflects the regional topography. Groundwater flows to the south and towards the lower reaches of the Waipoua rivers and the Te Ore Ore zone. The shape of the groundwater flow contours (Figure D17) and gauging data show that the Waipoua and Ruamahanga rivers predominantly receive inflow from groundwater (they are ‘gaining’) and therefore receive a significant baseflow contribution from aquifers in the Upper Ruamahanga zone.

Rainfall infiltration is an important groundwater recharge source in the Upper Valley catchment. The main influence on the spatial variability of recharge is the steep rainfall gradient across the valley from 1200-1300 mm/year against the Tararua Range to 600-700 mm/year at the eastern hills.

D.6.4 Hydrology

The Waipoua River is the first major western tributary of the Ruamahanga River in the Wairarapa Valley. This river has an estimated 7-day MALF of 490 L/s at the Ruamahanga River confluence. During periods of low flow the Waipoua River exhibits a complex pattern of losses and gains which reflect the influence of major faults on aquifer thickness. In particular, the river exhibits appreciable flow gain upstream of the Masterton Fault.

The Ruamahanga River flows through the central part of the zone and then becomes confined to a shallow valley between Lansdowne hill and the eastern hills. The river has a mean flow of about 7-day MALF of 1,294 L/s at Mt Bruce (upstream of the zone boundary), and 3,027 L/s at Wardell’s bridge (just upstream of the Waingawa River confluence, downstream of this zone).

The Kopuaranga River meanders across the poorly sorted gravel plains of the Upper Ruamahanga zone for 15 km to its confluence with the Ruamahanga River near Opaki. The 7-day MALF in the Kopuaranga River is 605 L/s (measured at Palmers Bridge just upstream of the zone boundary).

There are several minor spring systems north of Masterton emanating on the alluvial fan system between the Waipoua and Ruamahanga rivers. These include the 'Golf Course Spring' and the Waipipi Stream. The Waipipi Stream originates north of the Mokonui Fault and flows parallel to the Ruamahanga River for about 6 km, remaining on the northern side of Lansdowne hill before it joins the Ruamahanga River where it crosses the Masterton Fault. The few gauging results available for this stream suggest a flow of only about 20 to 30 L/s during the summer months with most of the gain occurring above the Mokonui Fault. The Golf Course Spring emanates on the fan north of Lansdowne hill and flows southwards to the Waipoua River at Masterton. There are no flow gaugings available but the spring is thought to maintain a flow in the order of 20 to 50 L/s during summer. There are also minor spring-fed streams on Lansdowne hill which flow down to the Masterton area and join the Waipoua River. One of these is the Opaki Stream which had a gauged flow of 10 L/s in April 2002.

D.6.5 Zone management objective

The principal management objective for groundwater allocation in the Upper Ruamahanga zone is to ensure the sustainable use of groundwater resources while protecting the instream values of hydraulically connected surface water ecosystems.

Within the Upper Ruamahanga zone, the Waipoua and Ruamahanga rivers have a direct connection to the groundwater environment and the protection of baseflow in these systems is of primary importance.

D.6.6 Numerical modelling

Simulated water balance

The numerical groundwater flow model (Gyopari and McAlister 2010a) was used to quantify the natural water balance for the Upper Ruamahanga water management zone by running the model for a period of 16 years (1992 to 2008) with no abstraction. The principal water balance components for the Upper Ruamahanga zone are rainfall recharge and groundwater-surface water fluxes. Figure D18 shows the modelled annual rainfall recharge for the Upper Ruamahanga zone for the period 1992 to 2008 from which an annual average of 23.5 x 10^6 m^3 was calculated. The lower quartile annual recharge for this dataset is 17.74 x 10^6 m^3/year.

The simulated natural fluxes (in the absence of groundwater abstraction) between surface water and groundwater within the Upper Ruamahanga zone are illustrated in Figure D19. The net negative fluxes for all three river systems show that they mostly gain more flow than they lose over the reaches located within the Upper Ruamahanga zone. As a consequence, low flow discharge in these rivers is supported by local groundwater baseflow discharge, particularly in the Waipoua River. The baseflow is lowest during summer and the Ruamahanga River may on occasion become a net 'losing river' in late summer as groundwater levels in the surrounding unconfined aquifer fall. Figure D19 shows the summed losses and gains for each river within the zone boundaries.

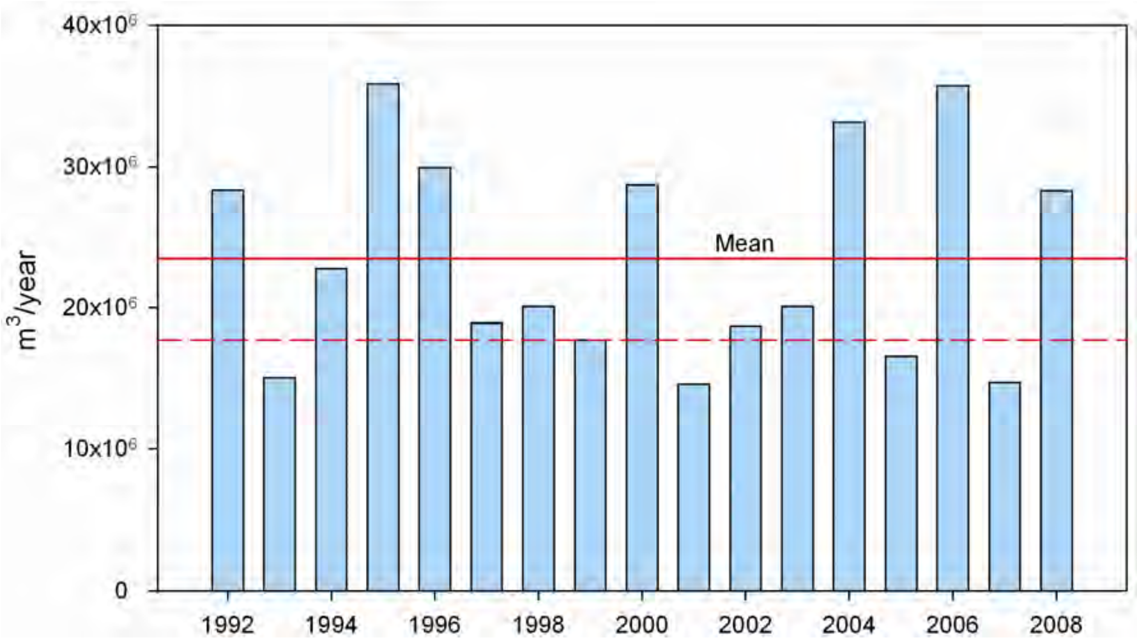

Figure D18: Modelled annual rainfall recharge 1992–2008 for the Upper Ruamahanga zone in the Upper Valley catchment. Mean annual recharge (red solid line) and lower quartile annual recharge value (dashed red line) are also shown.

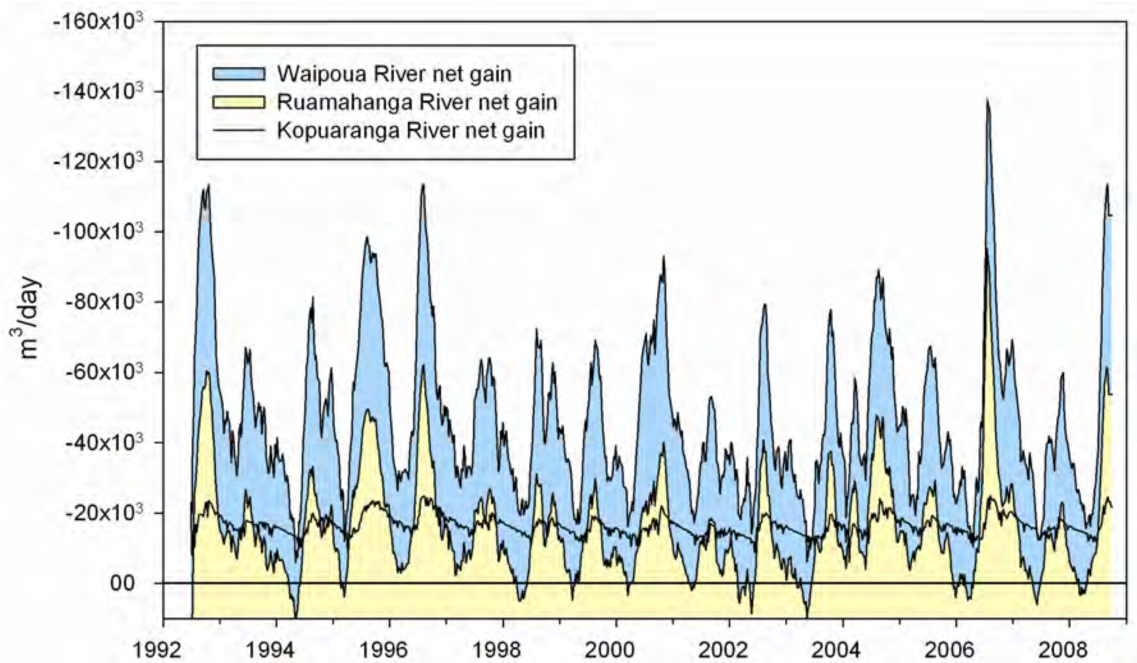

Figure D19: Simulated net natural surface water fluxes in the Upper Ruamahanga zone when no groundwater abstraction is occurring. The negative fluxes represent flow from groundwater to surface water (i.e. 'gaining' systems). In late summer the Ruamahanga River often becomes a 'losing' river and recharges groundwater. While the rivers may exhibit flow gains and losses over individual reaches, this plot shows the net gain over the entire reach located within the Upper Ruamahanga zone only.

D.6.7 Surface water depletion

The transient groundwater flow model for the Upper Valley catchment was used to simulate abstraction and characterise the relationship between groundwater abstraction and surface water depletion. Since the aquifer system of the Upper Ruamahanga zone is essentially the same as that of the Waingawa zone (aquifer properties are identical), the surface water depletion characteristics derived from abstraction scenarios for the Waingawa zone can also be applied to the Upper Ruamahanga zone.

The combined seasonal surface water depletion effect for the Waingawa zone averages 60% of the pumping rate – with a range of 50 to 70%. The adoption of a representative combined surface water depletion factor of 0.6 is therefore considered appropriate for the Upper Ruamahanga zone.

D.6.8 Groundwater management options for the Upper Ruamahanga zone

Groundwater-surface water interaction zones

- The mapped Q1 alluvium associated with the main river systems (Waipoua Ruamahanga and Kopuaranga rivers) should be classified as Category A. Where the recent alluvium is not mapped with confidence or is very narrow, a 500 m buffer should be used to define the zone boundary from the river centre-line (this distance is based on analytical and numerical modelling). The proposed extent of the Category A classification is shown on Figure D17 (red dashed line).

- The Category A classification should extend to a depth of 20 m.

- Category B status should be applied to the area between the Waipoua and Ruamahanga rivers, and also around the lower Kopuaranga catchment in recognition of the numerous spring-fed streams in these areas. The Category B classification should extend to 20 m depth and a depletion factor of 0.6 utilised to reflect the cumulative effect of groundwater abstraction on discharge at a catchment scale.

- The northern part of the Kopuaranga catchment and Lansdowne hill should be classified as Category C to reflect the relatively indirect hydraulic to surface water in this area.

Groundwater allocation

- Heterogeneous fan deposits in the Upper Ruamahanga zone should be managed as a single groundwater system. Model simulations show that the deeper semi-confined aquifers exhibit a significant connection to the surface water environment over relatively short pumping durations.

- Since there is little information relating to the Ruamahanga River flow in this zone, and due to the low-yielding nature of the aquifers (outside Category A), groundwater allocation should be primarily referenced to land surface recharge (LSR) calculated from the 16-year model run (1992-2008) as the lower quartile annual value. This is 17.74 x 10^6 m^3/year.

- Modelling of the adjacent Waingawa zone suggests that an allocation of between 15 to 20% of the LSR is appropriate in order to avoid excessive surface water depletion effects.

- The average surface water depletion factor for groundwater abstraction in the Upper Ruamahanga zone (for Category B + C areas) is 0.6.

- Annual allocation should be based on a pumping duration of 180 days.

Table D7 outlines suggested allocation options for the Upper Ruamahanga water management zone. Option 2 is recommended which equates to about 2.5% depletion of the Ruamahanga River and 20% of LSR.

Table D7: Groundwater allocation options for the Upper Ruamahanga water management zone

Option	% LSR*	Groundwater allocation (m^3/day)	Annual allocation (m^3 x10^6)
1	15%	14,800	2.66
2	20%	19,700	3.55

* Reference LSR – lower quartile annual land surface (rainfall) recharge for the period 1992 to 2008.

Appendix E

Appendix E: Middle Valley groundwater allocation framework

This Appendix sets out a proposed framework for the sustainable allocation of groundwater in the Middle Valley catchment of the Wairarapa Valley. It contains a summary of the hydrogeological setting of the Middle Valley as a whole and then discusses potential allocation regimes for each of the proposed management zones within the Middle Valley.

E.1 Summary of Middle Valley catchment hydrogeology

The hydrogeology of the Middle Valley catchment is described in detail by Gyopari and McAlister (2010b). A summary of the key features of the catchment are provided below.

The Middle Valley catchment of the Wairarapa Valley covers an area of about 270 km^2 and is bounded by the Waingawa River in the north, the terrace edge of the Waiohine plain to the south of Greytown, the Tararua Range to the northwest, and by the eastern hill country to the southeast.

A heterogeneous sequence of late Quaternary and Holocene unconsolidated sediments comprise the primary groundwater environment of the catchment. Variable degrees of sediment sorting, reworking, compaction and deformation by faulting and folding have resulted in the evolution of a complex aquifer system. In particular, major structures, such as the Masterton and Carterton faults, have dislocated and folded the sedimentary sequence and created the Parkvale sub-basin. A key feature of the catchment hydrogeology is the high degree of connectivity between the surface water and groundwater environment, particularly in areas where recent (Q1 age) alluvium is present along the riparian margins of the major river systems.

Natural groundwater discharges occur as river baseflow, spring flow and diffuse seepage into wetlands. Some reaches of the main river channels recharge groundwater by losing part of (or sometimes, all of) their flow into adjacent aquifers. Concurrent river gauging surveys show that the three principal river systems – the Ruamahanga, Waiohine and the Waingawa rivers – exhibit complex patterns of flow gain and loss with respect to adjacent shallow aquifers.

Rainfall recharge is an important component of the catchment water balance. Soil moisture balance modelling predicts that average annual recharge rates vary from 600 to 700 mm (30 to 40% of rainfall) against the Tararaua Range, to less than 100 mm (<10% of rainfall) on the southern side of the catchment. The average recharge volume over a 15-year period between 1992 and 2007 was 68.2 x 10^6 m^3/year (Gyopari and McAlister 2010b).

Conceptually, the Middle Valley catchment is characterised as a ‘closed’ groundwater basin in which the dominant water balance components are rainfall recharge and fluxes between surface water and groundwater. Groundwater abstraction constitutes more than about 15% of the catchment water balance during the summer months. Shallow, highly permeable unconfined aquifers comprising recent (Q1) gravels are of particular significance in terms of potential groundwater-surface water interaction due to their high degree of connectivity with the surface water environment (rivers, springs and wetlands).

E.2 Water management zones

Managing the cumulative effects of groundwater abstractions with a moderate to low hydraulic connection to surface water has been approached by delineating '*water management zones*' within each of the three Wairarapa Valley catchments (Upper, Middle and Lower). These zones are essentially management units based on groundwater and surface water sub-catchment mapping which may also (or alternatively) represent distinct hydrogeological domains. Zone delineation criteria include surface water catchment boundaries, hydraulic or physical groundwater flow system boundaries, the conceptual hydrogeological functioning of the zone and its context within the larger groundwater catchment.

The zones are designed so that the management of surface water resources can be easily integrated with groundwater allocation, thereby allowing the cumulative effects of groundwater abstraction on sub-catchment baseflow to be accounted for at a catchment scale (i.e. enabling conjunctive management of groundwater and surface water resources).

It is important to recognise the water management zones are not, in most instances, isolated management units. Most zones have 'soft' boundaries based on hydraulic divides or represent transitional areas within a continuous groundwater flow system. Where significant interactions between zones are recognised, the sensitivity of cross-zone groundwater fluxes to the cumulative effects of abstraction has been evaluated and provision made in the proposed allocation options.

Figure E1 shows the spatial extent of the six proposed 'water management zones' for the Middle Valley catchment which are summarised in Table E1. These zones are based primarily upon surface water and groundwater catchments but are also locally constrained by geological boundaries. The delineation of water management zones is therefore based upon the conceptual hydrogeological model and the recognition of distinct hydrogeological domains. The rationale behind each zone boundary is provided in the relevant zone sections.

Table E1: Water management zones, management objectives and criteria for the Middle Valley catchment

Zone name	Area (km²)	Management objectives	Allocation criteria
Waiohine	39.2	Baseflow depletion in the Waiohine River and Greytown springs	Waiohine River MALF Greytown springs MALF
Mangatarere	78.3	Baseflow depletion in the Mangatarere Stream and spring-fed tributaries	Mangatarere Stream MALF at Waiohine confluence
Parkvale	37.4	Baseflow depletion in Parkvale Stream and Booths Creek Confined aquifer drawdown	Parkvale springs mean flow Drawdown threshold
Taratahi	29.3	Instream values of surface water ecosystems: springs and wetlands associated with major faults	Masterton and Carterton faultline springs MALF
Fernhill-Tiffen	38.1	Drawdown	Rainfall recharge
Middle Ruamahanga	43.8	Instream values of Ruamahanga River	Ruamahanga River MALF

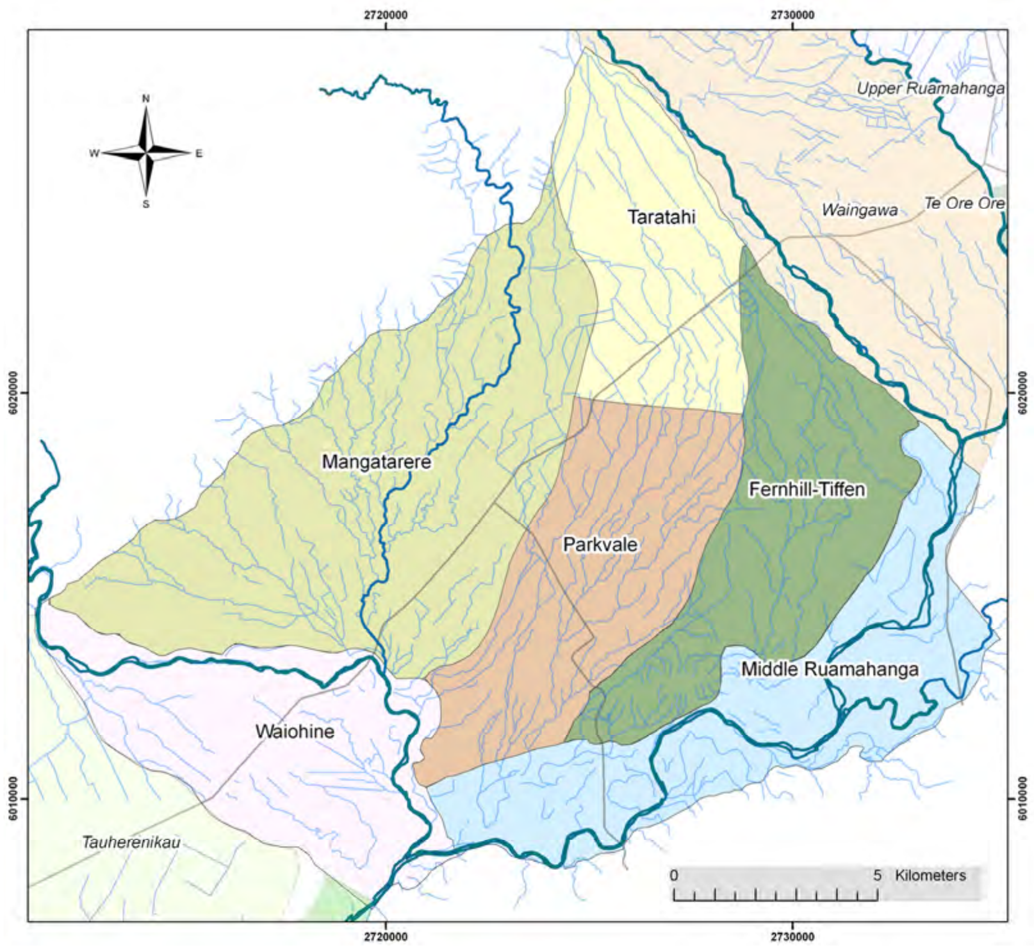

Figure E1: Water management zones in the Middle Valley catchment

Figure E2 shows the existing Regional Freshwater Plan (RFP) (WRC 1999) groundwater management zones and an outline of the proposed new water management zones to enable cross-referencing.

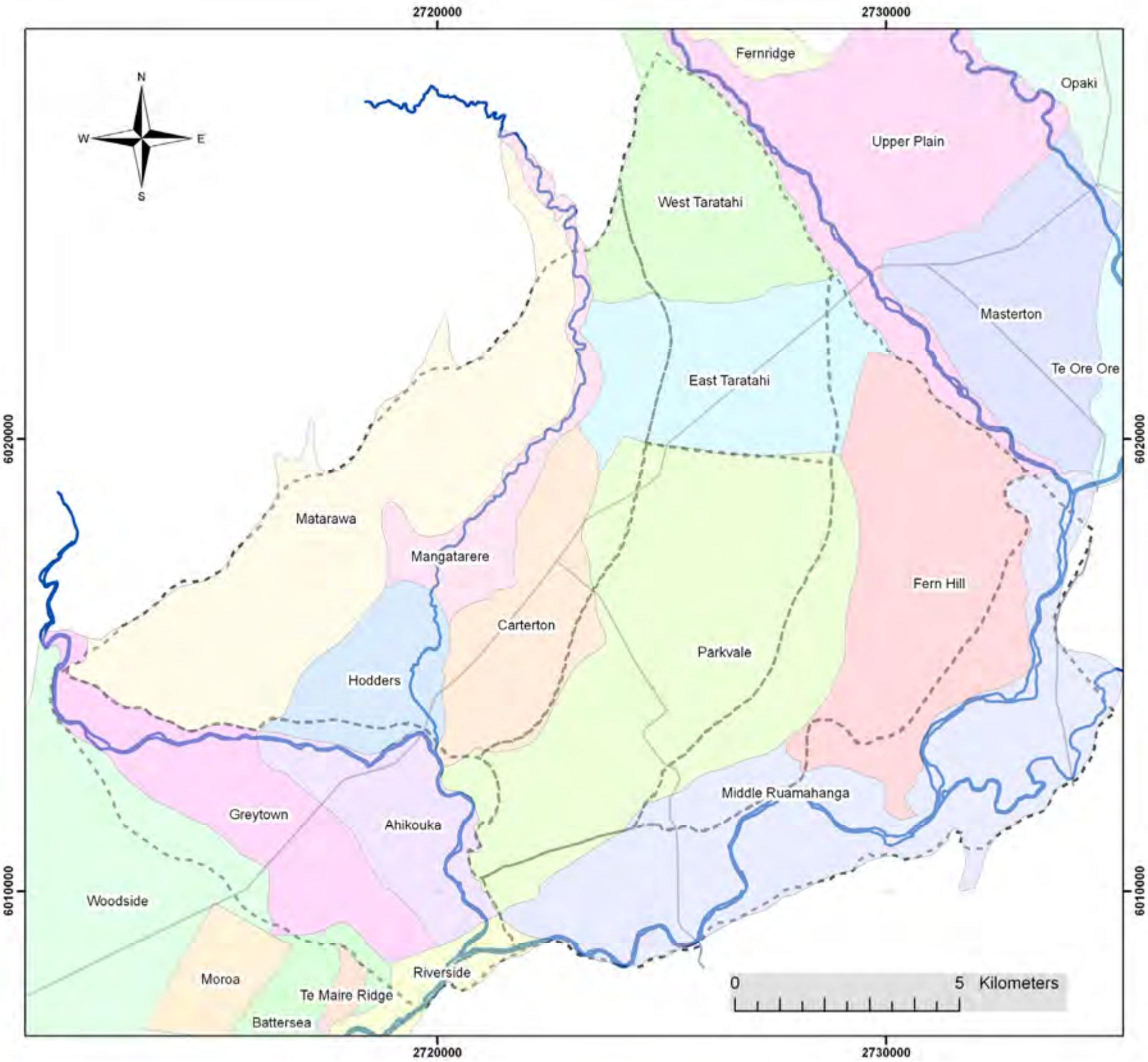

Figure E2: Map showing existing RFP (WRC 1999) groundwater management zones and an outline of the new water management zones (black dashed lines)

E.3 Middle Valley catchment numerical groundwater model

The numerical groundwater flow model for the Middle Valley catchment was used to explore groundwater management options for each water management zone by simulating the effects of groundwater abstraction on zonal water balances. Particular consideration was given to examining the sensitivity of groundwater-surface water fluxes to various abstraction scenarios. The model provided information on surface water depletion effects, aquifer drawdowns, rainfall recharge characteristics, and cross-zone throughflows and their sensitivity to groundwater abstractions. Details of the model and its calibration are provided in Gyopari and McAlister (2010b).

Initially, the numerical groundwater flow model was used to quantify the natural water balances by running the model for the 15-year calibration period (1992 to 2007) with no groundwater abstraction occurring. This scenario provided a ‘baseline simulation’ against which the effects of abstraction were evaluated, including information on the cumulative depletion effects of groundwater pumping on the surface water environment and cross-zone throughflow changes. For some sub-catchments, additional short scenarios were simulated to further refine the responses of the groundwater system to abstraction. These are documented in the following sections.

E.4 Waiohine water management zone

E.4.1 Overview

Delineation: The Waiohine water management zone encompasses the Waiohine plain in the Greytown area (Figure E3). The zone consists largely of shallow Q1 alluvium.

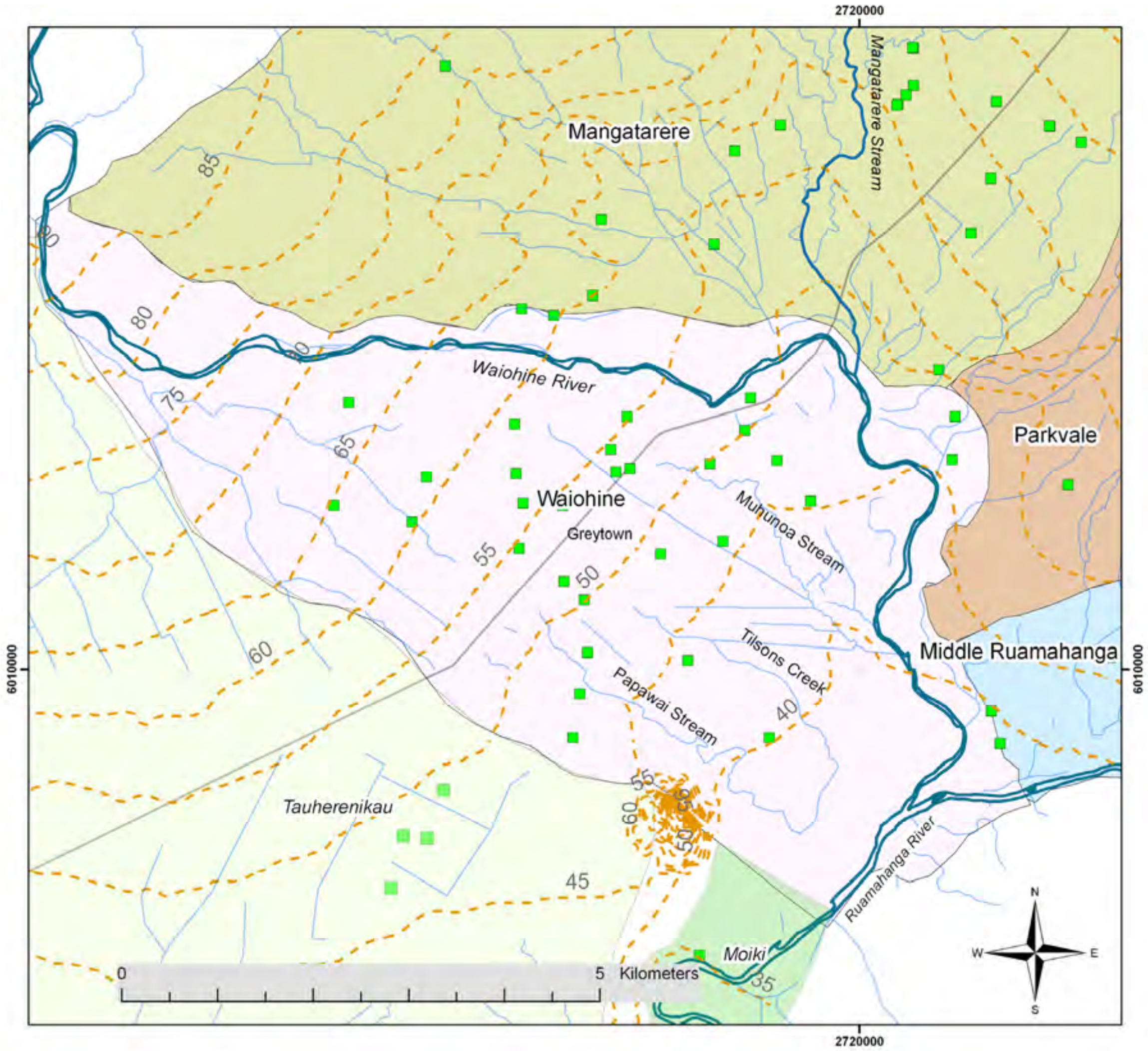

Figure E3: The Waiohine water management zone map showing existing groundwater bores with consented abstraction (green squares) and simulated groundwater flow contours (brown dashed lines, 5 m intervals in metres above mean sea level).

Area: 39.2 km^2.

Boundaries: The northern boundary is geologically delineated and follows a Q2 alluvial terrace. The southern boundary likewise follows a prominent terrace separating the Waiohine plain from the Tauherenikau fan to the south. This boundary represents a groundwater flow divide and is also the boundary between the Middle and Lower valley catchments.

The south-eastern zone boundary follows the contact between late Quaternary alluvium and the early-mid Quaternary or

	Tertiary eastern hills sequences. The Ruamahanga River flows along this boundary.
Principal surface water systems:	Waiohine River, Ruamahanga River, Papawai Stream, Tilsons Creek, Muhunoa Stream.
Aquifer sequences:	Shallow unconfined aquifer to 10 to 15 m depth. Deeper semi-confined aquifers near the Parkvale zone boundary.
Recharge:	Average annual recharge is 10.25 x 10^6 m^3.
Existing RFP zones:	Greytown, Ahikouka, Riverside (northern end only). Table E2 provides the allocation status of each of these zones.

Table E2: 'Safe yield' estimates and groundwater allocation status for existing RFP (WRC 1999) groundwater zones located in (or partially within) in the Waiohine water management zone

Existing RFP zone	RFP 'safe yield' (m^3/year)	Current allocation		% allocated
		(m^3/day)	(m^3/year)	
Greytown	20.0 x 10^6	25,500	4.78 x 10^6	24
Ahikouka	3.3 x 10^6	16,340	2.92 x 10^6	88
Riverside (north end only)	3.9 x 10^6	24,285	3.9 x 10^6	100

E.4.2 Current consented groundwater abstraction in the Waiohine water management zone

As at June 2010, there are 31 bores with consented abstraction in the Waiohine zone with a total daily allocation of approximately 37,000 m^3/day (locations are shown on Figure E3). Most of the abstraction occurs in the shallow Q1 gravels (28 bores <15 m depth) which have a combined allocation of 31,200 m^3/day (or 84% of the total zone allocation).

E.4.3 Hydrogeology summary

Holocene age (Q1) gravels occupy much of the Waiohine zone and constitute a shallow (<15 m deep) highly permeable unconfined aquifer which is hydraulically connected to the surface water environment. The gravels are associated with present-day river channels and postglacial flood plains of the Waiohine River. The unconfined aquifer exhibits medium to high hydraulic conductivities which can sustain large groundwater abstractions. Most bores intersect only the upper, highly permeable 10 to 15 m thick Q1 sequence, although near the Waiohine-Parkvale zone boundary a few very productive bores tap deeper semi-confined aquifers which are separated from the overlying Q1 gravels by intervening layers of fine-grained, low permeability interglacial sediments (Q5) . Groundwater levels are controlled by the Waiohine River and there is good evidence to show that at a distance of more than 4 km, the river persists in having a strong influence on the shallow Q1 aquifer.

Numerous concurrent gauging runs on the Waiohine River show that the river loses 15 to 25% of its flow between the sites ‘Railway Bridge’ and ‘SH2 Bridge’ (upstream of the confluence with the Mangatarere Stream). The loss is in the order of 0.5 to 1.5 m^3/s during summer low flow conditions. Most of the water lost in the upper stretches of the Waiohine River migrates through the highly permeable aquifers in the Greytown area and emerges as discharge in the Greytown springs (Tilsons Creek, Papawai Stream, Muhunoa Stream) or direct groundwater seepage into the lower reaches of the Waiohine River. The loss-gain characteristics of the Waiohine River are fairly neutral between the SH2 bridge and the confluence of the Muhunoa Stream with no significant groundwater discharges from either the Carterton or Parkvale aquifers evident from gauging data for this reach.

E.4.4 Hydrology

The Waiohine River emerges onto the Wairarapa plains at the Waiohine Gorge. From here, it flows a further 20 km in an easterly direction to the Ruamahanga River confluence about 5 km east of Greytown. Approximately 6 km upstream of the confluence, the Mangatarere Stream joins the Waiohine River. Concurrent gaugings indicate that the Waiohine River loses about 15 to 25% of its flow to groundwater upstream of the Mangatarere confluence during periods of low flow. The 7-day mean annual low flow in the Waiohine River at the gorge and Ruamahanga confluence has been estimated as 3,57 m^3/s and 3.55 m^3/s respectively (Keenan 2009).

A short section of the Ruamahanga River flows along the southeastern boundary of the Waiohine water management zone. In this reach the river gains flow both from tributary inputs and from groundwater baseflow discharge.

Substantial quantities of groundwater discharge into the sub-parallel Papawai, Tilsons and Muhunoa streams from the shallow alluvial aquifers on the eastern section of the Greytown-Waiohine plain. The combined mean outflow from this spring system is estimated to be in the order of 1.5 m^3/s (individual contributions are listed in the Table E3). These springs flow to the south-east and discharge either into the Waiohine River (Muhunoa Stream) or Ruamahanga River (Papawai Stream and Tilson’s Creek).

Table E3: Estimated spring flows – Middle Valley catchment (from Butcher 2007 and Keenan 2009)

Stream	Mean annual flow (L/s)	Mean annual low flow (L/s)
Papawai Stream	380	200
Tilsons Creek	235	140
Muhunoa Stream	800	550

E.4.5 Zone management objective

The principal management objective for groundwater allocation in the Waiohine zone is to ensure the sustainable use of groundwater resources while protecting the instream values of hydraulically connected surface water ecosystems.

Within the Waiohine zone, the Waiohine and Ruamahanga rivers and the Greytown springs (Papawai, Tilsons and Muhunoa streams) have a direct connection to the groundwater environment and the protection of baseflow in these systems is therefore of primary importance.

E.4.6 Numerical modelling

Baseline (no-abstraction) water balance

The numerical groundwater flow model (Gyopari and McAlister 2010b) was used to quantify the natural water balance for the Waiohine zone by running the model for a period of 15 years (1992 to 2007) with no groundwater abstraction occurring. This scenario provides a baseline simulation against which the effects of abstraction can be evaluated. Of particular relevance to assessing the sustainability of abstraction, the model provides information on the cumulative depletion effects of groundwater pumping on the surface water environment.

The principal water balance components for the Waiohine zone are inputs from rainfall recharge and flow losses through the bed of the Waiohine River. Groundwater discharge occurs into the lower reaches of the Waiohine River and also into the Ruamahanga River. Figure E4 shows the inter-annual variability of modelled annual rainfall recharge for the Waiohine zone for the period 1992 to 2007. The average annual rainfall recharge for this period was $10.25x10^6$ m^3 and the lower quartile annual rainfall is $6.76x10^6$ m^3.

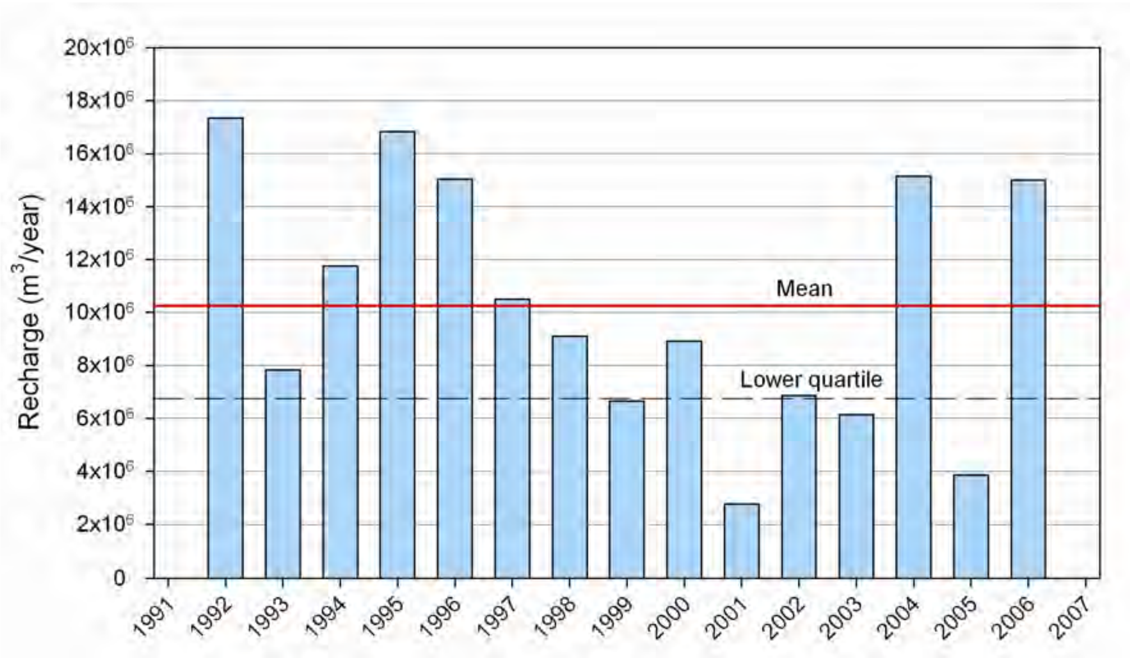

Figure E4: Modelled annual rainfall recharge for the Waiohine zone in the Middle Valley catchment providing a mean recharge of 10.25 x 10^6 m^3/year

Figure E5 shows the total simulated groundwater discharge and the discharge to the spring-fed streams in the Greytown area. The model predicts a mean net groundwater discharge to surface water of approximately 116,000 m^3/day (1.34 m^3/s) which includes a mean discharge to the springs of about 80,000 m^3/day (0.925 m^3/s).

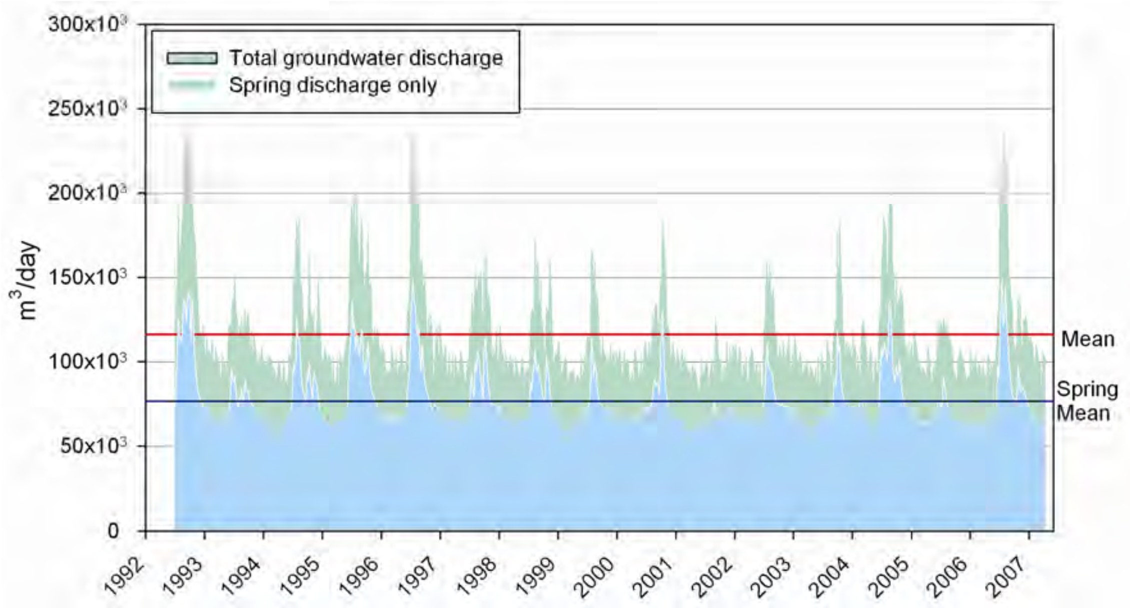

Figure E5: Simulated total zonal groundwater discharge to surface water (green) and discharge to the Papawai springs only (blue) in the Waiohine zone when there is no groundwater abstraction (1992 to 2007). The plot shows an average total groundwater discharge of 116,000 m^3/day (about 1.3 m^3/s) and a mean discharge to the Papawai springs of 80,000 m^3/day (0.93 m^3/s).

E.4.7 Modelled abstraction effects 1992-2007

Abstraction from the Waiohine zone was simulated for the 15-year transient groundwater model run (Figure E6). This figure shows both the total modelled abstraction for the zone and abstraction associated only with the shallow Q1 unconfined aquifer. Seasonal abstraction has increased significantly since about 1997 and is estimated to now peak at about 19,000 m^3/day. The current consented abstraction is about 37,000 m^3/day and therefore the estimated actual use is about 51% of the consented daily rate.

The modelled depletion effect of groundwater abstraction from the Waiohine water management zone on the surface water environment is shown in Figure E7. This plot shows simulated surface water depletion resulting from historical abstraction from all consented bores in the Waiohine zone by comparing the fluxes predicted by a baseline non-pumping simulation with those predicted when the model is run with historical abstraction. The model predicts that the total seasonal depletion is equivalent to the abstraction rate thereby showing a high degree of connectivity between the aquifer and the surface water environment in this zone. During some years, the depletion rate appears to exceed the pumping rate because some of the depletion shown can be attributed to cross boundary effects resulting from groundwater abstraction in adjacent water management zones.

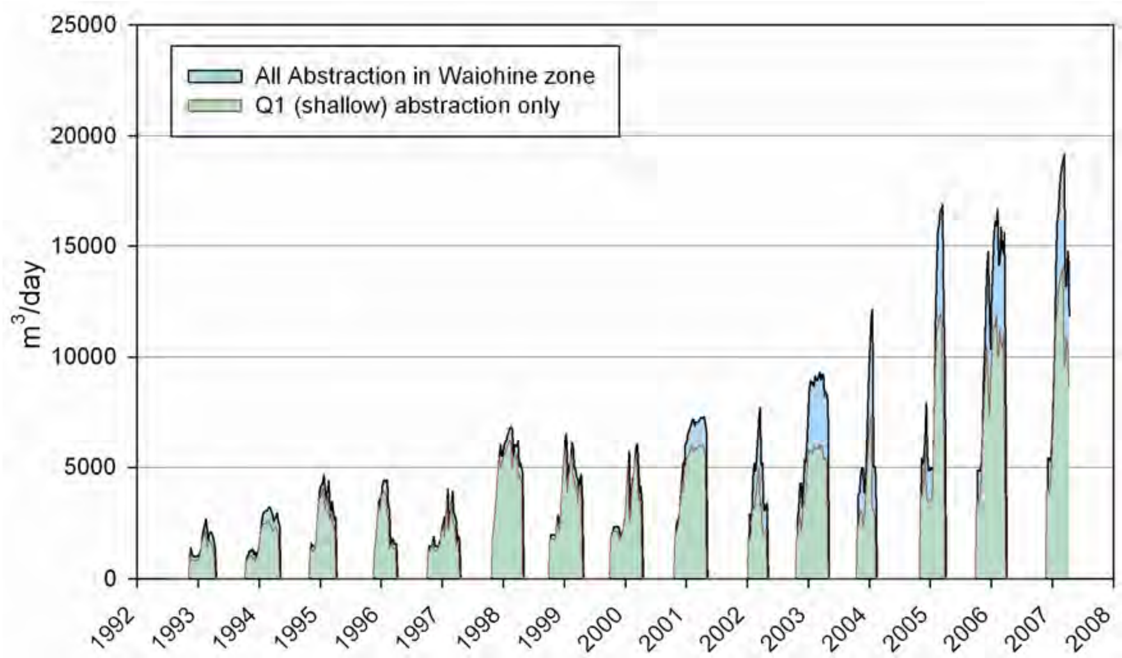

Figure E6: Simulated abstraction in the Waiohine zone – total abstraction and Q1 unconfined abstraction

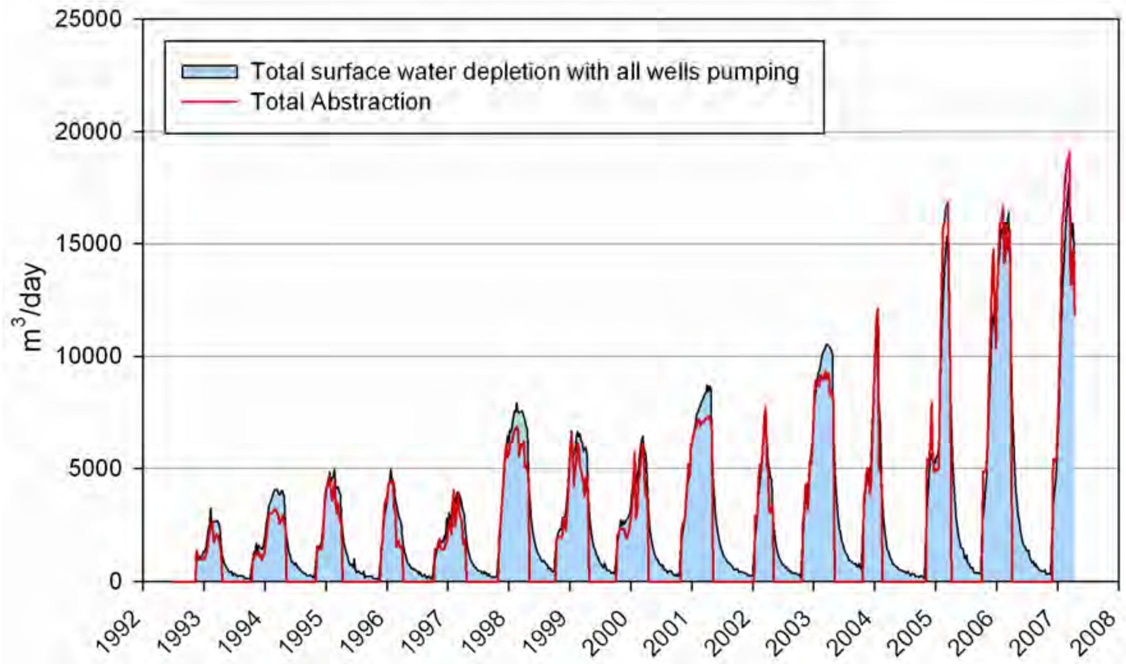

Figure E7: Simulated total surface water depletion resulting from abstraction from all consented bores in the Waiohine water management zone. Effects of groundwater abstraction from adjacent zones are responsible for depletion apparently exceeding pumping rate in some years.

Figure E8 shows the surface water depletion associated with a model scenario in which only consented bores located in the Q1 unconfined aquifer were pumped. The bottom plot shows in detail the simulated depletion curve over the 2002-03 irrigation season for Q1 pumping only. It is apparent that pumping from Q1 bores causes a rapid depletion effect which attains 90% or more of the pumping rate with a virtually immediate reduction in calculated stream depletion when pumping ceases.

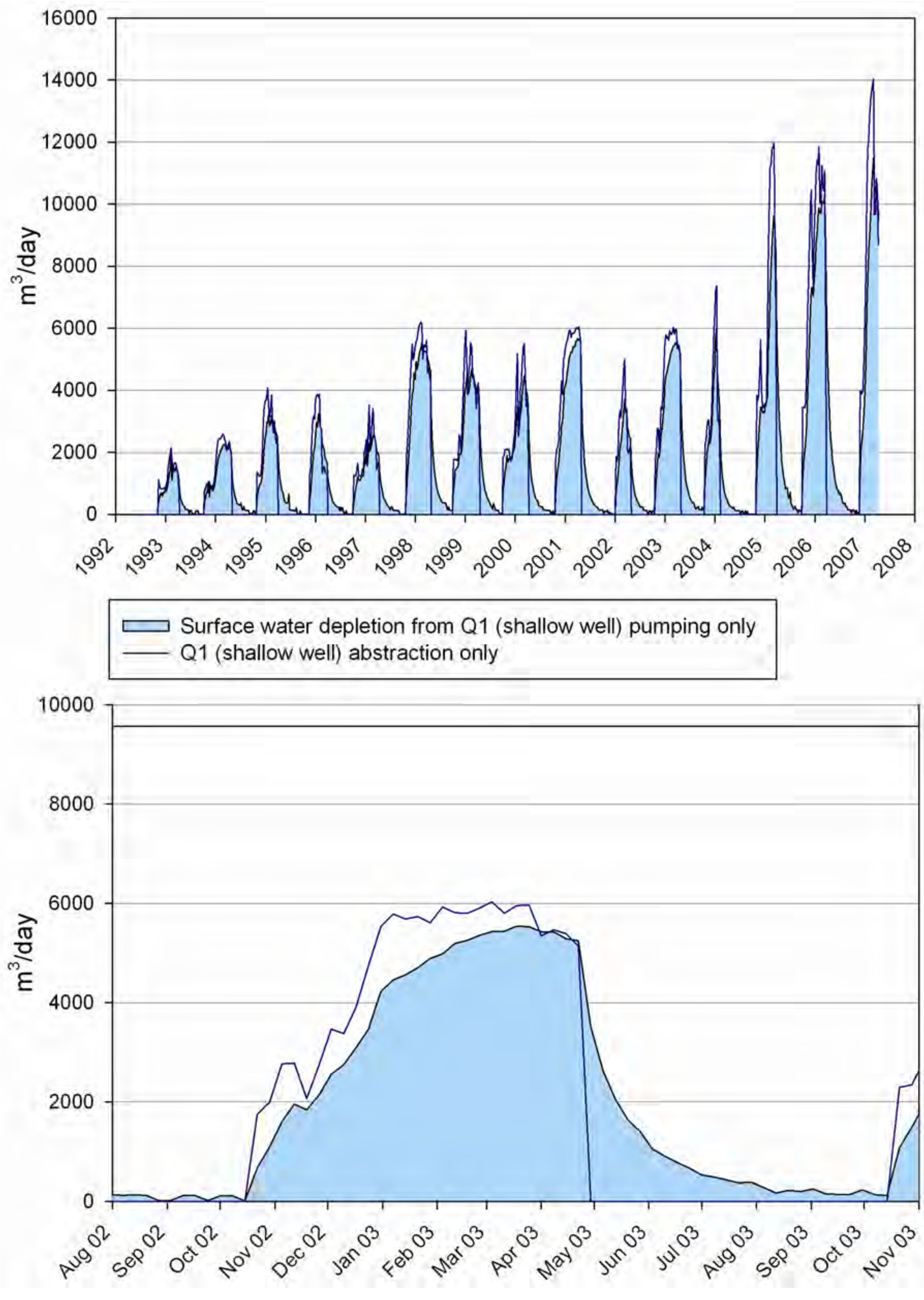

Figure E8: Simulated total surface water depletion (rivers and springs) resulting from historic abstraction in the Waiohine zone from shallow Q1 bores only. The bottom plot shows the same data for the 2002–03 irrigation season.

The depletion effect on the Greytown springs only is shown in Figure E9. This plot shows that depletion of the springs amounts to approximately 60 to 65% of the pumping rate. Springflow reduction is therefore the major largest contributor to the total surface water depletion effect.

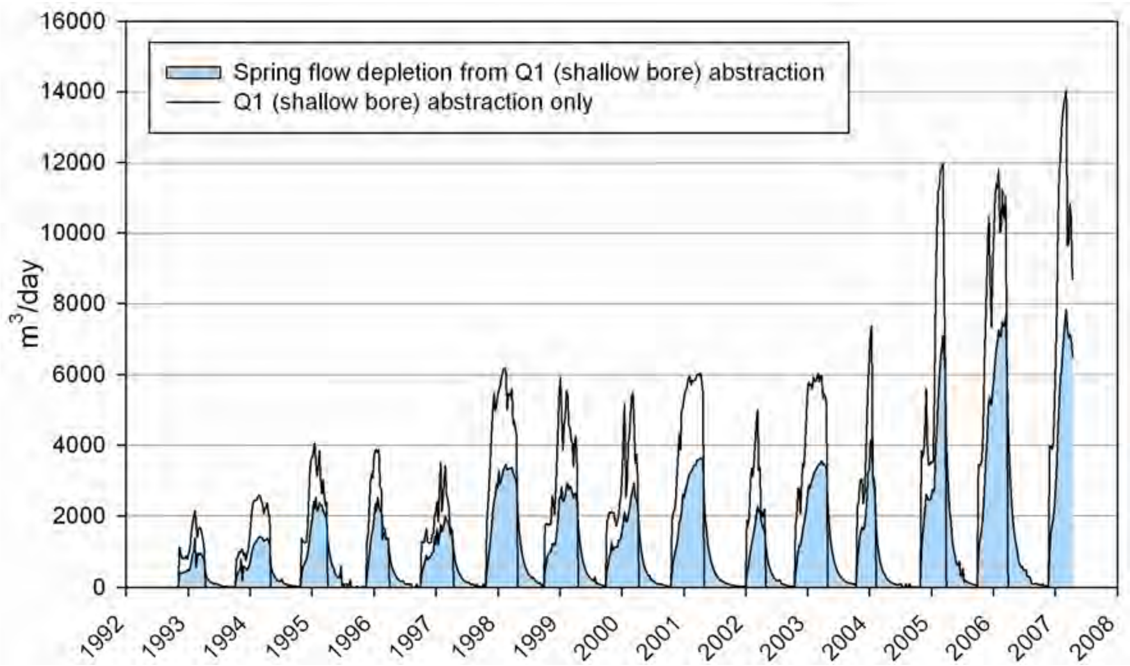

Figure E9: Simulated spring flow depletion (Papawai-Tilsons-Muhunoa) resulting from historic abstraction from Q1 (shallow) bores only in the Waiohine zone. The results show that spring flow depletion is about 60 to 65% of the bore abstraction rate.

E.4.8 Groundwater management options for the Waiohine zone

Groundwater-surface water interaction zones

- Due to the very high degree of connectivity between the aquifers (unconfined and semi-confined) and the surface water environment, the entire Waiohine zone should be classified as Category A (direct hydraulic connection).

- Modelling indicates that deeper bores in this zone also exhibit a high connectivity to the surface water environment and therefore the Category A status should extend to all aquifer depths.

Groundwater allocation

- No groundwater allocation is necessary under the Category A (high hydraulic connection category) as all groundwater abstraction will be managed according to surface water allocation policies.

E.5 Mangatarere water management zone

E.5.1 Overview

Delineation: The Mangatarere water management zone is coincident with the surface water and groundwater catchments of the Mangatarere Stream (Figure E10).

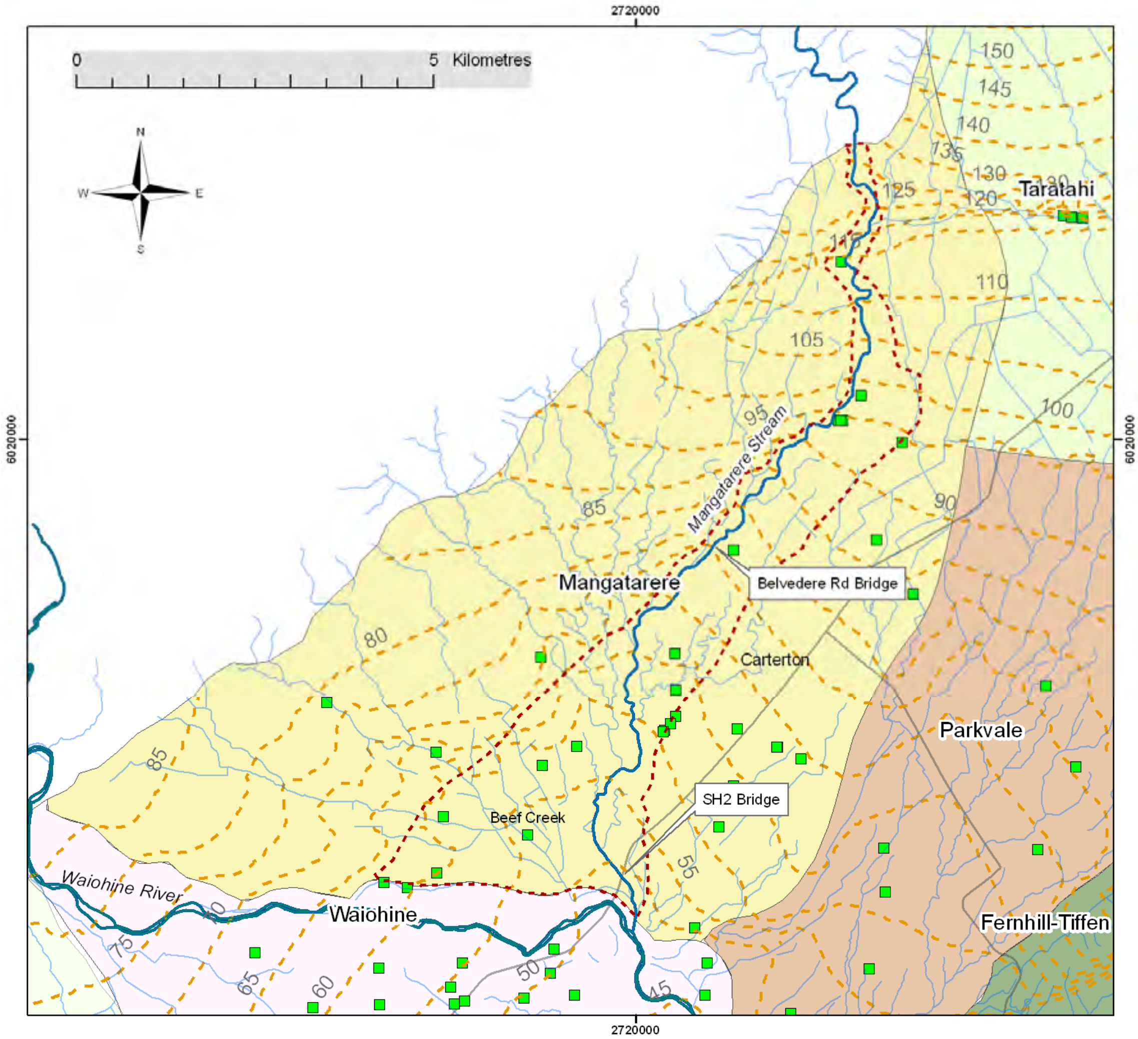

Figure E10: The Mangatarere water management zone map showing existing groundwater bores with consented abstraction (green squares), groundwater flow contours (brown dashed lines, 5 m intervals in metres above mean sea level) and the extent of the alluvial deposits classified as Category A (red dashed line)

Area: 78.3 km^2

Zone boundaries: The eastern boundary follows a groundwater divide which separates this zone from the proposed Parkvale and Taratahi zones. This boundary is also partially coincident with a geological structure ('Brickworks anticline') which separates the Parkvale and Carterton sub-basins.

The southern boundary follows a prominent Q2 Waiohine terrace and also approximates a groundwater divide between the Waiohine and Mangatarere zones. It is acknowledged that some groundwater flow occurs across the terrace to the Waiohine sub-catchment, but is a relatively minor component of the water balance for both zones.

The western boundary is a prominent geological boundary defined by the Tararua foothills and the Wairarapa Fault.

Principal surface water systems: Mangatarere Stream and tributaries (Enaki Stream, Kaipaitangata Stream and Beef Creek).

Aquifer sequences: One aquifer sequence – unconfined to semi-confined. Regarded as a single leaky system on the basis of numerical model simulations.

Recharge: The estimated average annual rainfall recharge for the zone is 3.1×10^7 m^3

Existing RFP zones: Matarawa, Mangatarere, Hodders, Carterton (part of East and West Taratahi). Table E4 summarises the allocation status of each of these zones.

Table E4: 'Safe yield' estimates and groundwater allocation status for existing RFP groundwater zones (WRC 1999) located in (or partially within) in the Mangatarere water management zone

Existing RFP zone	'Safe yield' (m^3/year)	Current allocation		% allocated
		(m^3/day)	(m^3/year)	
Matarawa	10.0×10^6	2,536	0.439×10^6	4
Mangatarere	7.6×10^6	6,100	1.293×10^6	17
Hodders	4.0×10^6	9,800	1.826×10^6	46
Carterton	3.9×10^6	17,175	2.854×10^6	73
Total	25.5×10^6	35,611	6.412×10^6	

E.5.2 Current consented groundwater abstraction in the Mangatarere water management zone

As at June 2010, there are 28 bores with consented abstraction in the Mangatarere zone with a combined allocation of approximately 34,500 m^3/day. Approximately 60% of this allocation occurs from the deeper semi-confined aquifer in the Carterton area (14 bores).

E.5.3 Hydrogeology summary

In general, the Mangatarere zone comprises a heterogeneous sequence of late Quaternary age fan gravels in the west which are of generally low permeability and have poor resource potential. To the east of the Mangatarere Stream the fan sequence appears to become more permeable with a more pronounced layering of waterbearing gravels towards the Carterton area. Here, a shallow unconfined aquifer is underlain by an aquitard and a deeper semi-confined aquifer (Q6) within which most higher yielding bores in this zone are located. Complex structural features (such as the Carterton Fault and Brickworks anticline/fault complex) deform the alluvial deposits and influence groundwater flow patterns.

Recent/Holocene (Q1) higher permeability alluvium occurs along the riparian margins of Mangatarere Stream which forms a shallow unconfined aquifer hydraulically connected to the stream. This aquifer is relatively shallow (5 to 10 m) and is not as well developed as the Q1 associated with the major river systems (such as the Waiohine and Ruamahanga rivers).

Recharge occurs through both rainfall infiltration and loss through the bed of the Mangatarere Stream in the reaches between the Tararua Range foothills and Belvedere Road bridge – see Figure E10. Groundwater discharge occurs into numerous small streams on the western fan, and into the lower reach of the Mangatarere Stream. Some throughflow also occurs southwards into the Waiohine sub-catchment.

E.5.4 Hydrology and surface water allocation management

The Mangatarere Stream and its tributary streams are the principal surface water drainage systems in the zone. The estimated mean annual low flow statistics for the Mangatarere Stream at the Ruamahanga River confluence are (Keenan 2009):

- 305 L/s (1-day)
- 370 L/s (7-day)

The low flows at the mouth of the catchment incorporate the inputs from tributaries (principally Beef Creek, the Enaki Stream and the Kaipaitangata Stream). The Mangatarere Stream loses flow to groundwater in its mid reaches and is known to run dry in the vicinity of Andersons Line. Downstream of this point, the stream begins to gain baseflow from groundwater and contributions from small (often spring-fed) tributaries. During dry periods, the flow at the Waiohine River confluence is greater than at the Mangatarere Gorge indicating a net flow gain from groundwater baseflow discharge.

In recognition of the distinct characteristics of the Mangatarere catchment, the stream is managed in two reaches – the upper reach[28] between the foothills of the Tararua Range and the Belvedere Road bridge, and the lower reach from Belvedere Road bridge to the Waiohine confluence.

[28] 'Upper reach' in this report describes the section of the stream from the Mangatarere Gorge to Belvedere Rd bridge (i.e. does not include the uppermost headwaters of the stream within the Tararua Forest Park).

E.5.5 Zone management objective

The principal management objective for groundwater allocation in the Mangatarere zone is to ensure the sustainable use of groundwater resources while protecting the instream values of hydraulically connected surface water ecosystems.

Within the Mangatarere zone, the Mangatarere Stream and its tributary streams have a direct connection to the groundwater environment and the protection of baseflow in these systems is of primary importance.

E.5.6 Numerical modelling

Baseline (no-abstraction) water balance

The numerical groundwater flow model was initially used to quantify the water balance for the Mangatarere zone in the absence of groundwater abstraction by running the model for a period of 15 years (1992 to 2007) with no groundwater abstraction simulated. This no-abstraction scenario represents a baseline simulation against which the effects of various abstraction scenarios can be evaluated. Of particular relevance to assessing the sustainability of abstractions, the model enables the cumulative depletion effects from groundwater pumping on the surface water environment to be quantified.

The principal water balance components for the zone are rainfall recharge and groundwater discharge to surface water. Figure E11 shows the modelled annual rainfall recharge for the Mangatarere zone for the period 1992 to 2006. The average annual rainfall recharge for this period is 31 x 10^6 m^3 and the lower quartile annual rainfall 23.33 x 10^6 m^3.

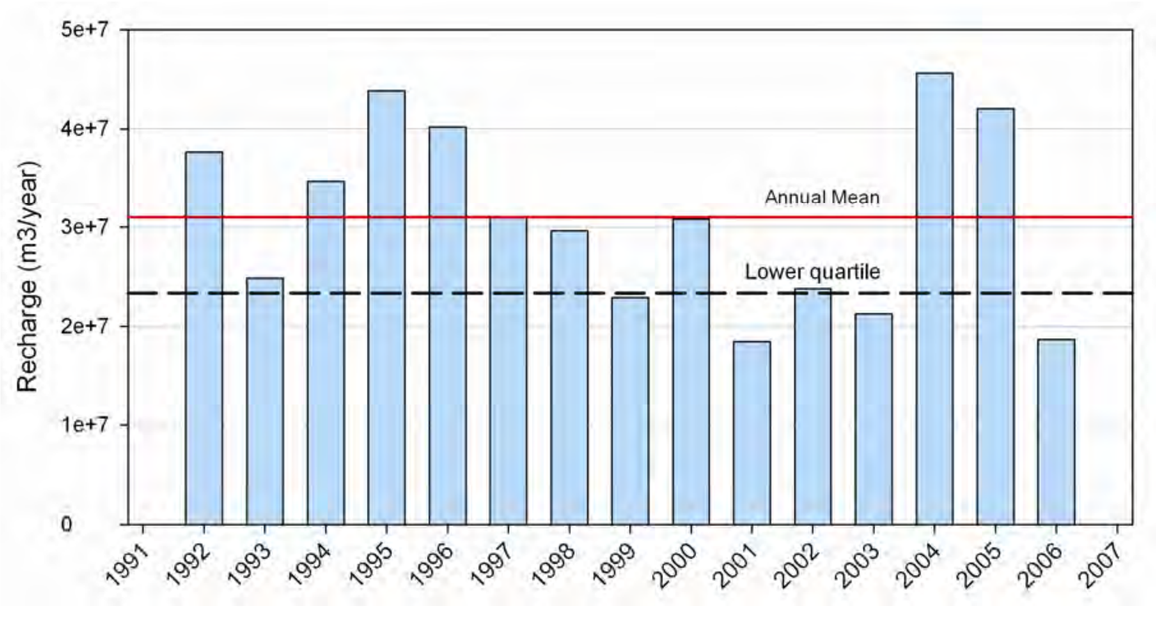

Figure E11: Modelled annual rainfall recharge (1992-2006) for the Mangatarere water management zone (mean annual recharge is 31x10^6 m^3 and lower quartile annual rainfall is 23.33x10^6 m^3)

Figure E12 shows the simulated groundwater discharge to the Mangatarere Stream and its spring-fed tributaries. Also shown is the independently calculated 7-day MALF for the Mangatarere Stream at its confluence with the Waiohine River (370 L/s; 32,000 m^3/day). At this location, the entire flow is expected to be groundwater-derived during low-flow periods when there is little or no flow in the Mangatarere Stream above Andersons Line (the river gains from groundwater below this location). The consistency between modelled surface water discharge and the estimated MALF provide confidence in the model calibration.

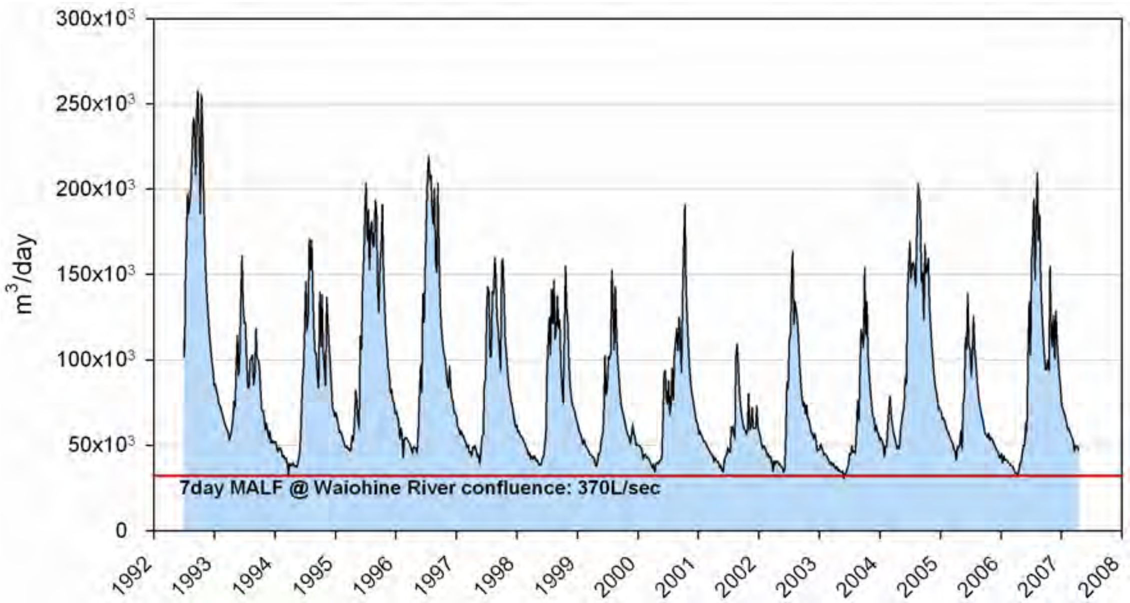

Figure E12: Simulated groundwater discharge to surface water (Mangatarere Stream and tributaries) when there is no groundwater abstraction in the Mangatarere water management zone (1992 to 2007). Note the modelled summer baseflow corresponds closely with the 7-day MALF for the Mangatarere Stream at the Waiohine confluence (at this location all the tributaries are also taken into account).

Current abstraction

Current (estimated) abstraction was simulated for the 16-year transient model run and the water balance outputs were compared to the baseline (no-abstraction) simulation described above. The effects of groundwater abstraction on the surface water environment were then evaluated by comparing the two sets of water balance outputs.

Figure E13 shows the modelled surface water depletion resulting from current abstraction in the Mangatarere management zone. Figure E14 shows a detailed portion of Figure E13 for the period June 2002 and December 2005 to illustrate the response of the groundwater system to abstraction. This scenario shows that seasonal abstraction has increased rapidly between about 2000 and 2006/07 to peak at about 14,000 m^3/day. The total depletion of surface water is around 60 to 70% of the abstraction rate during the final year of the simulation. The magnitude of the resulting stream depletion effect is calculated at about 8,000 m^3/day which is approximately 25% of the 7-day MALF of the Mangatarere Stream at the Waiohine River confluence.

Seasonal depletion peaks towards the end of each seasonal irrigation season but does not cease immediately when pumping is switched off; rather, there is a considerable time lag and depletion recedes into the winter months. During wet years, when rainfall recharge is above average, aquifer storage is replenished more quickly and the depletion rate reduces more rapidly (e.g. 2004 and 2005; see Figure E11).

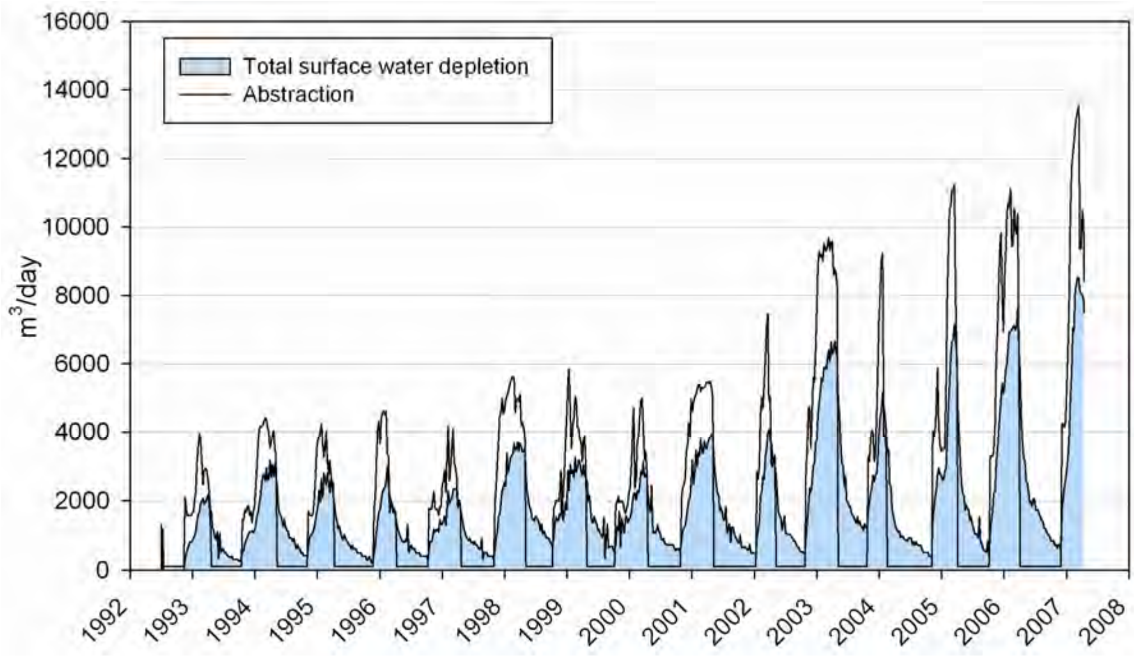

Figure E13: Simulated historic abstraction and associated surface water depletion in the Mangatarere zone of the Middle Valley catchment (1992–2007). A depletion equivalent to 60 to 70% of the abstraction rate occurs within the timeframe of seasonal abstraction and recedes over the winter months.

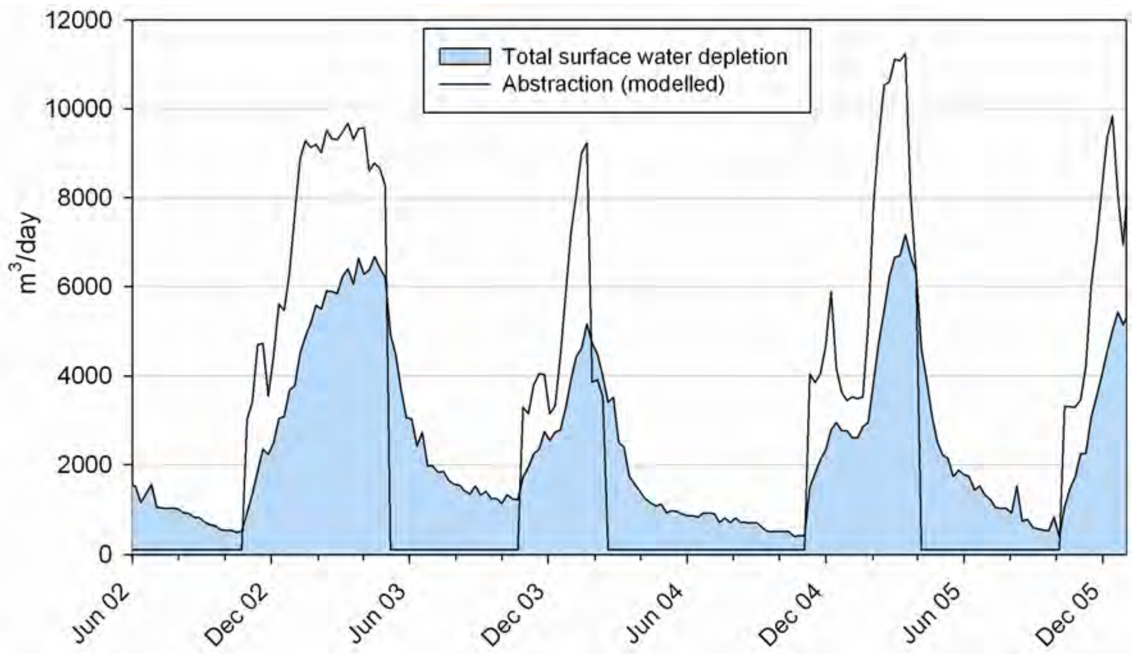

Figure E14: Detail of Figure E13 – Simulated historic abstraction and associated surface water depletion in the Mangatarere zone of the Middle Valley catchment between 2002 and 2005. The plot demonstrates the lag between the termination of seasonal pumping and surface water depletion due to slow storage replenishment. The depletion recession rate is largely controlled by seasonal rainfall recharge.

It can be observed from the response of the groundwater system to cumulative groundwater abstraction that regulation of pumping to control surface water depletion is unlikely to be an effective means of mitigating potential stream depletion effects in deeper (Q6) waterbearing layers and away from the immediate margins of the Mangatarere Stream and tributaries. This is primarily due to the system lag and the necessity for storage to be replenished by winter recharge to offset depletion effects.

Figure E15 shows the proportion of current depletion effects associated with the upper and lower reaches of the Mangatarere catchment as defined in the surface water allocation policy. Since most groundwater abstraction occurs in the lower portion of the Mangatarere sub-catchment (see Figure E10), the bulk of the depletion occurs in the lower reach of the Mangatarere Stream (between Belvedere Road Bridge and the Waiohine River confluence) where a majority of groundwater baseflow discharge occurs.

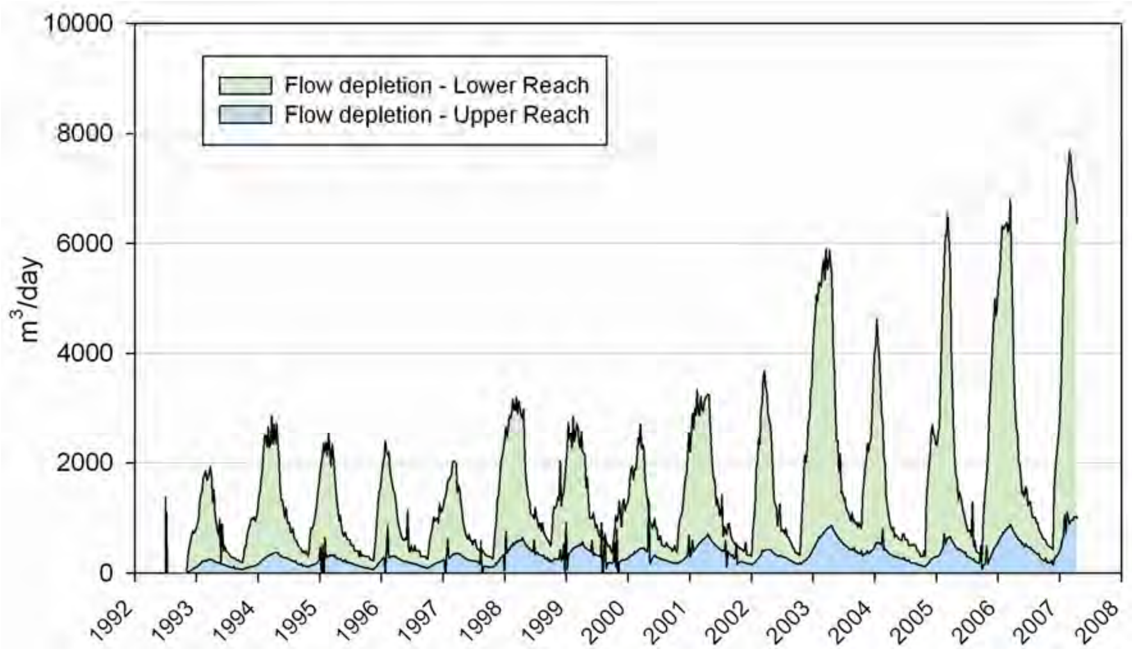

Figure E15: Simulated surface water depletion associated with historic abstraction for the upper and lower reaches of the Mangatarere catchment. The plot shows that almost all depletion occurs in the lower reach below the Belvedere Road bridge.

E.5.7 Abstraction scenarios

The transient groundwater flow model for the Middle Valley catchment was used to simulate 'synthetic' abstraction scenarios to further characterise the relationship between groundwater abstraction and surface water depletion. For these scenarios, the transient run time was shortened to just over one year (3 May 2005 to 5 September 2006; model days 4,690 to 5,180) – spanning one irrigation season and continuing until the start of the next one.

The following scenarios were simulated:

Scenario 1: Current abstraction from shallow bores only (excluding any located in the Q1 deposits in direct connection to the river). This scenario demonstrates the proportion of the surface water depletion effect associated with abstraction from shallow aquifers and deeper semi-confined aquifers. The output for Scenario 1 is shown in Figure E16.

Scenario 2: A synthetic distributed abstraction scenario from the shallow unconfined aquifer (outside Q1 alluvium) from numerous low-yielding bores. The total abstraction varies from 10,000 to 8,000 m^3/day (10% of the daily average rainfall recharge). For this scenario, abstraction occurs for 150 days between 2 November 2005 and 29 March 2006. Abstraction bores are distributed across the zone on model slice 4 (refer to Gyopari and McAlister 2010b for more detail), with each node pumping at 150 m^3/day (to avoid drying of layers due to the low hydraulic conductivity of the fan sequences). Outputs for Scenario 2 are shown in Figures E17 and E18.

Scenario 3: Synthetic abstraction from the Q6 semi-confined aquifer around Carterton at a constant pumping rate of 12,000 m^3/day. This scenario uses 24 bores distributed on model slice 8 beneath and to the east of the Mangatarere Stream in the Carterton area. Each bore pumps at 500 m^3/day for 150 days (Nov-Apr).

Scenario 4: The same as Scenario 3 except the pumping rate is increased to 20,400 m^3/day.

Figure E16 shows the simulated surface water depletion for Scenario 1 - when only bores located in shallow unconfined aquifers are pumped. These bores constitute only about 20% of the total pumping rate from the zone and therefore their contribution to total surface water depletion is small – peaking at about 1,500 m^3/day – although this equates to about 70% of the pumping rate (2005/06). Figure E13 shows that the total surface water depletion from all groundwater abstraction in the zone during this period was about 7,000 m^3/day. Shallow bores within the catchment (outside the Q1 alluvium, Zone A) therefore currently contribute to only about 20% of the total surface water depletion. Results of this scenario also indicate that deeper bores in the more productive semi-confined aquifers around Carterton contribute to surface water depletion (i.e. they are not abstracting from an isolated confined resource).

Figures E17 and E18 show the model outputs from Scenario 2. Figure E17 shows the depletion effects from pumping the shallow unconfined aquifer, at a rate of between about 10,000 and 8,000 m^3/day on total surface water discharge within the zone (i.e. the Mangatarere Stream and its tributaries), and on the Mangatarere Stream only. Note the abstraction rate declines because the water table declines in areas of low hydraulic conductivity (the western fans) such that bores begin to run dry. Figure E18 shows the same information in terms of the ratio between the depletion rate (q) and the average pumping rate (Q) which is termed the ‘depletion factor’ (i.e. q/Q). This plot is useful since it is independent of pumping rate and shows the proportion of the pumping rate which contributes to surface water depletion (the depletion factor). The data shown indicate that after 150 days pumping total depletion in the zone is equivalent to between 60 to 70% of the overall abstraction rate.

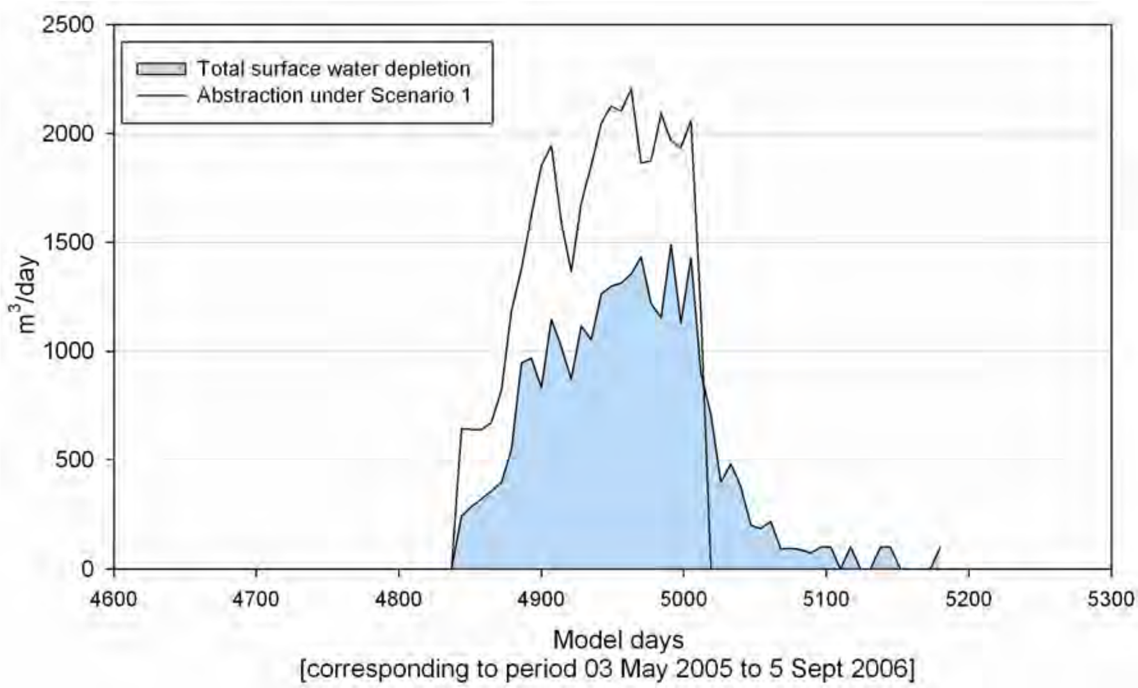

Figure E16: Scenario 1 output – total surface water depletion in the Mangatarere zone from pumping bores with existing consents to abstract that are located in the shallow unconfined aquifers (excluding Q1 deposits)

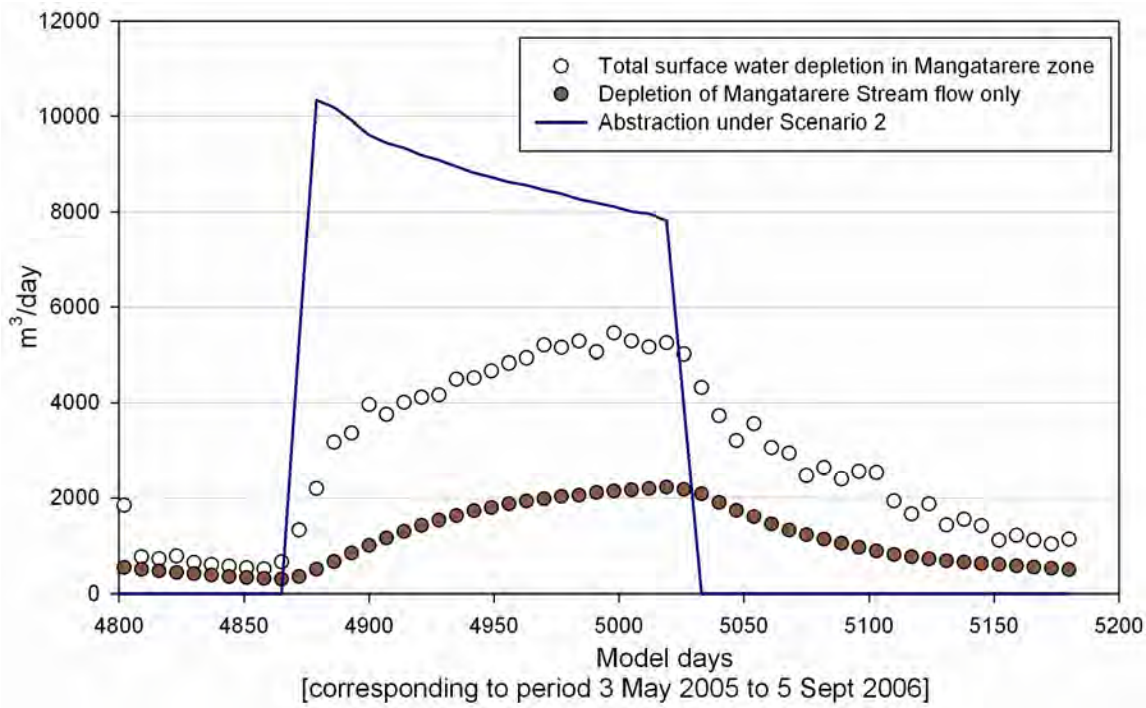

Figure E17: Scenario 2 output – total surface water depletion in the Mangatarere zone and in the Mangatarere Stream from pumping an array of synthetic bores located in the shallow unconfined aquifers (outside Q1 deposits)

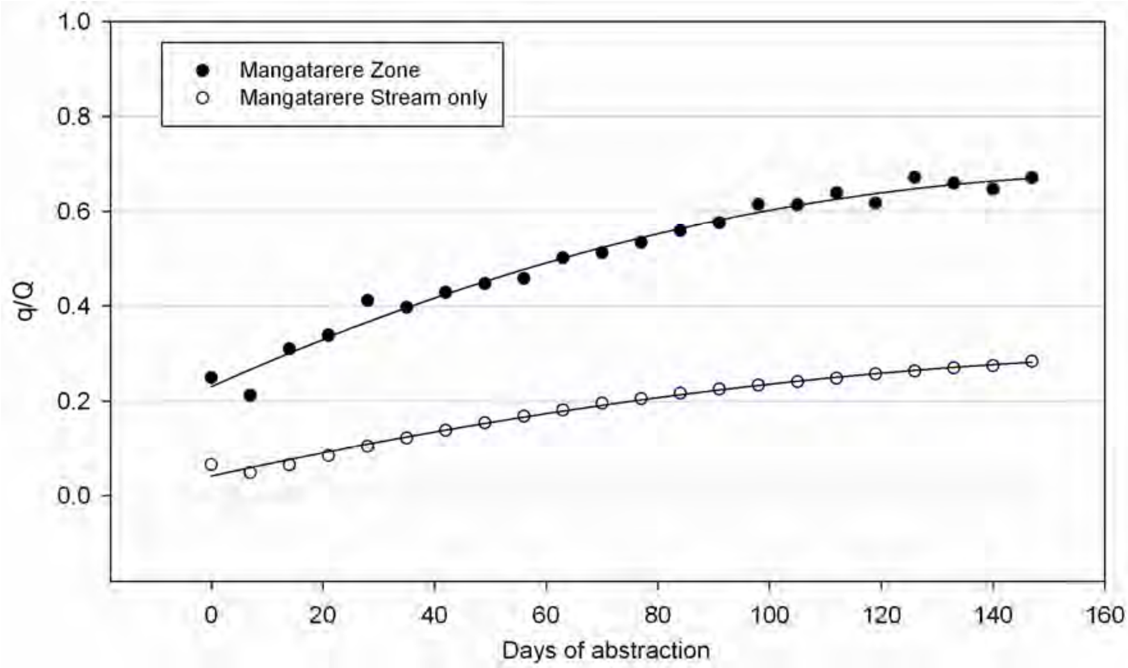

Figure E18: Scenario 2 – ratio of surface water depletion (q) to pumping rate (Q) for both the Mangatarere zone (total depletion for streams and springs) and Mangatarere Stream only – shallow aquifer abstraction only

Figures E19 and E20 relate to pumping scenarios 3 and 4 in the deeper semi-confined Q6 aquifer around the Carterton area. Approximately 80% of current abstraction occurs from this deeper more productive aquifer and it is therefore important to assess the effect that groundwater takes from this aquifer may have on the surface water environment. The model scenarios predict that the effect is significant and that the deeper aquifers in this area should not be regarded as a separate resource. Figure E19 shows that the depletion rate in the Mangatarere zone at the end of the irrigation season is about 50% of the pumping rate (i.e. depletion factor q/Q = 0.5). When pumping ceases, there is a slow recession in the depletion throughout the following months. It is significant to note here that by ceasing pumping there is very little immediate impact on the surface water depletion rate. Therefore, the regulation of these takes on the basis of surface water low-flow triggers would not provide an effective means to mitigate the effects of this pumping during low flow periods.

Figure E20 shows the ratio of depletion to pumping rate for Scenarios 3 and 4 (abstracting at 12,000 and 20,400 m^3/day respectively from the semi-confined aquifer). The plot demonstrates that the depletion factor is independent of pumping rate and that after 150 days of pumping, the depletion is about 50% of the total abstraction rate. The plots appear to have levelled off by 150 days and it appears unlikely that the cumulative depletion would increase substantially over longer pumping durations.

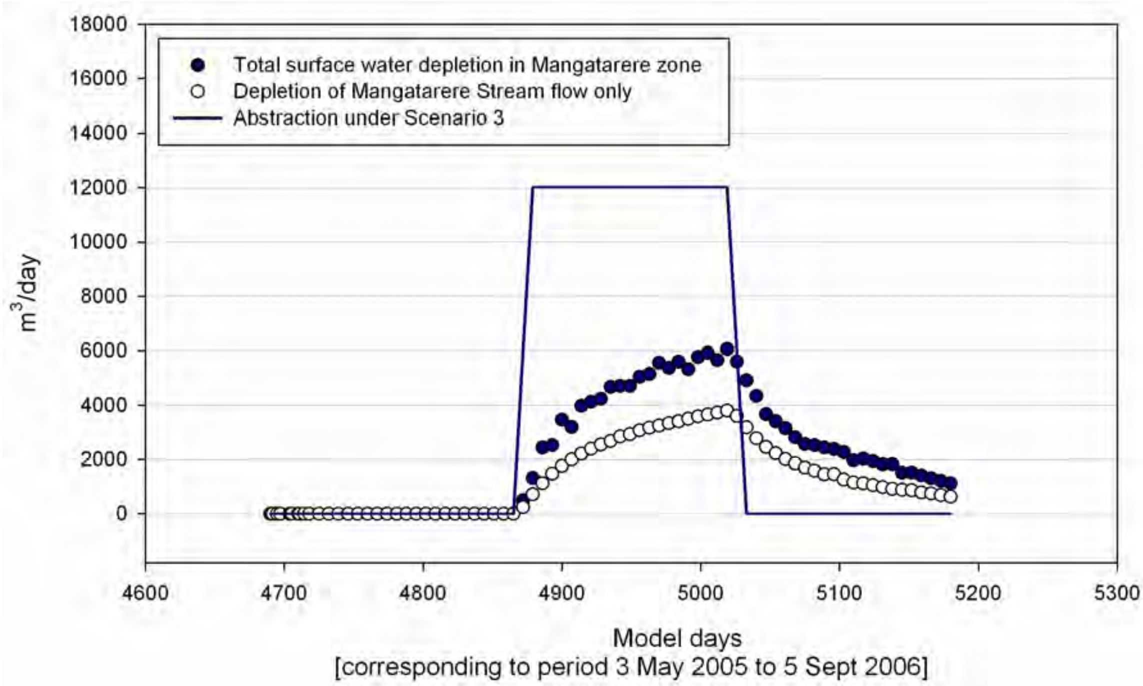

Figure E19: Scenario 3 output – surface water depletion in the Mangatarere zone and in the Mangatarere Stream resulting from pumping an array of synthetic bores located in the Q6 semi-confined aquifer at a rate of 12,000 m³/day for 150 days

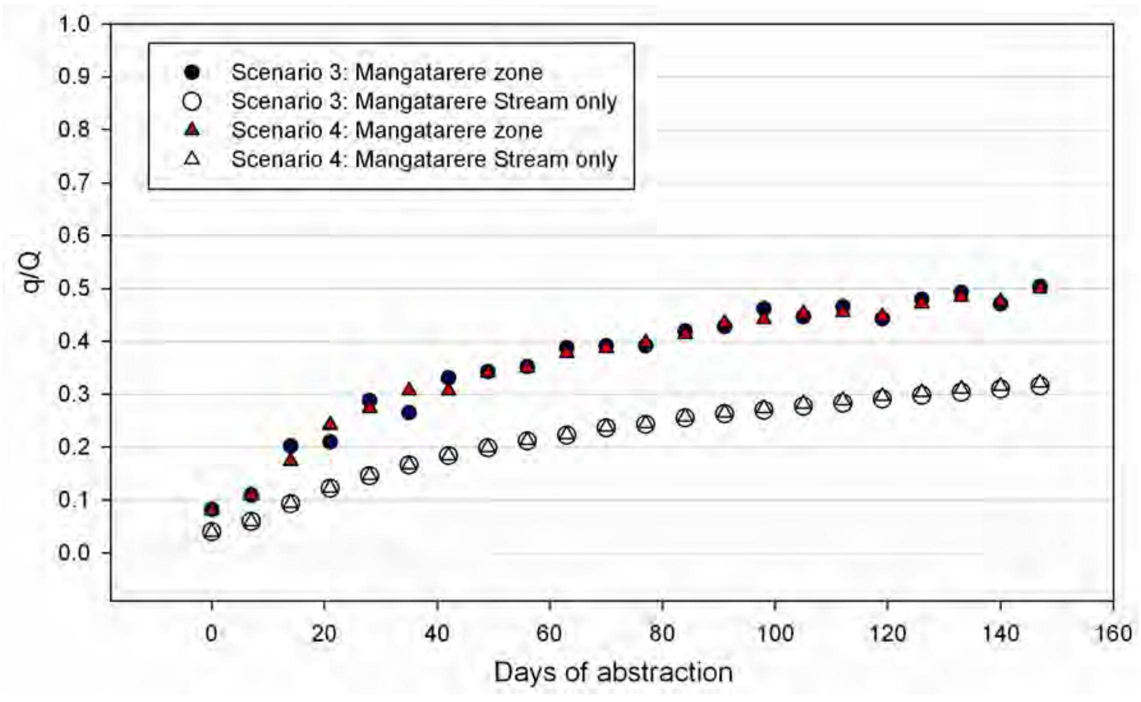

Figure E20: Scenarios 3 and 4 – ratio of surface water depletion (q) to pumping rate (Q) for both the Mangatarere zone (total depletion for streams and springs) and Mangatarere Stream only – abstraction from semi-confined Q6 aquifer at 12,000 m³/day (Scenario 3) and 20,400 m³/day (Scenario 4) for 150 days

E.5.8 Groundwater management options for the Mangatarere zone

Groundwater-surface water interaction zones

- Recent alluvium (Q1) associated with the Mangatarere Stream should be classified as Category A to a depth of 20 m to reflect the direct hydraulic connection with the Mangatarere Stream. Category A should also be extended to include the lower reaches of the Beef Creek spring system in the confluence area of the Mangatarere Stream and Waiohine River (existing Hodders groundwater zone) as recent pumping test data demonstrate that bores of at least 30 m depth exhibit significant vertical leakage likely to induce stream depletion due to resulting drawdown in the overlying Q1 gravels. Figure E10 shows the spatial extent of the Category A classification.
- Beneath Category A, Category B should extend from 20 m to 30m depth.
- Elsewhere, it is recommended the Mangatarere zone should be classified as Category B to 20 m depth in recognition of the numerous spring-fed streams in the catchment.
- Category C underlies the entire catchment below the Category B and C thresholds specified above.

Groundwater allocation

- Aquifers in the Mangatarere zone should be managed as a single groundwater system. Model simulations show that the deeper semi-confined aquifers exhibit a significant connection to the surface water environment over relatively short pumping durations.
- The groundwater allocation criterion for this zone should be referenced to the 7-day MALF for the Mangatarere Stream at the Waiohine River confluence. This flow incorporates groundwater baseflow to surface water for the entire zone. The estimated 7-day MALF at this location is 370 L/s (32,000 m^3/day).
- A depletion factor of 0.5 should be adopted for the Category B and Category C components of the Mangatarere water management zone to reflect the dominance of the more productive semi-confined aquifer in surface water depletion.
- Annual allocation should be based on a pumping duration of 180 days.

Table E5 outlines options for groundwater allocation in the Mangatarere water management zone based on the potential cumulative effect of groundwater abstraction on baseflow in the Mangatarere Stream.

Option 3 is recommended which represents a 20% cumulative depletion effect on the Mangatarere Stream at the Waiohine confluence. Effects of existing allocation (3.45Mm^3/year) will result in a 30% effect on the MALF which is considered excessive when considered together with core and Category A allocation. No further impact should be justified given that Mangatarere Stream has been identified as a particularly stressed system with known issues of poor water quality and low flows. It is therefore recommended that current groundwater allocations are reduced.

Table E5: Groundwater allocation options for the Mangatarere water management zone

Option	Cumulative depletion effect on Mangatarere Stream	Allocation* (m^3/day)	Allocation (m^3/year x 10^6)	% mean annual LSR**
1	10% MALF	6,400	1.15	5.0
2	15% MALF	9,600	1.72	7.0
3	20% MALF	12,800	2.3	10.0
4	25% MALF	16,000	2.9	12.0

* Allocation = x% MALF / depletion factor.

* * LSR – lower quartile annual land surface (rainfall) recharge (for reference only).

Current allocation is 3.45Mm^3/year

E.6 Parkvale water management zone

E.6.1 Overview

Delineation: The Parkvale water management zone is coincident with the surface water and groundwater catchments of the Parkvale Stream and Booths Creek up to the Carterton Fault (Figure E21). It also encompasses a productive confined aquifer sub-basin beneath the Parkvale plains. Groundwater in the zone discharges towards the Waiohine and Ruamahanga rivers.

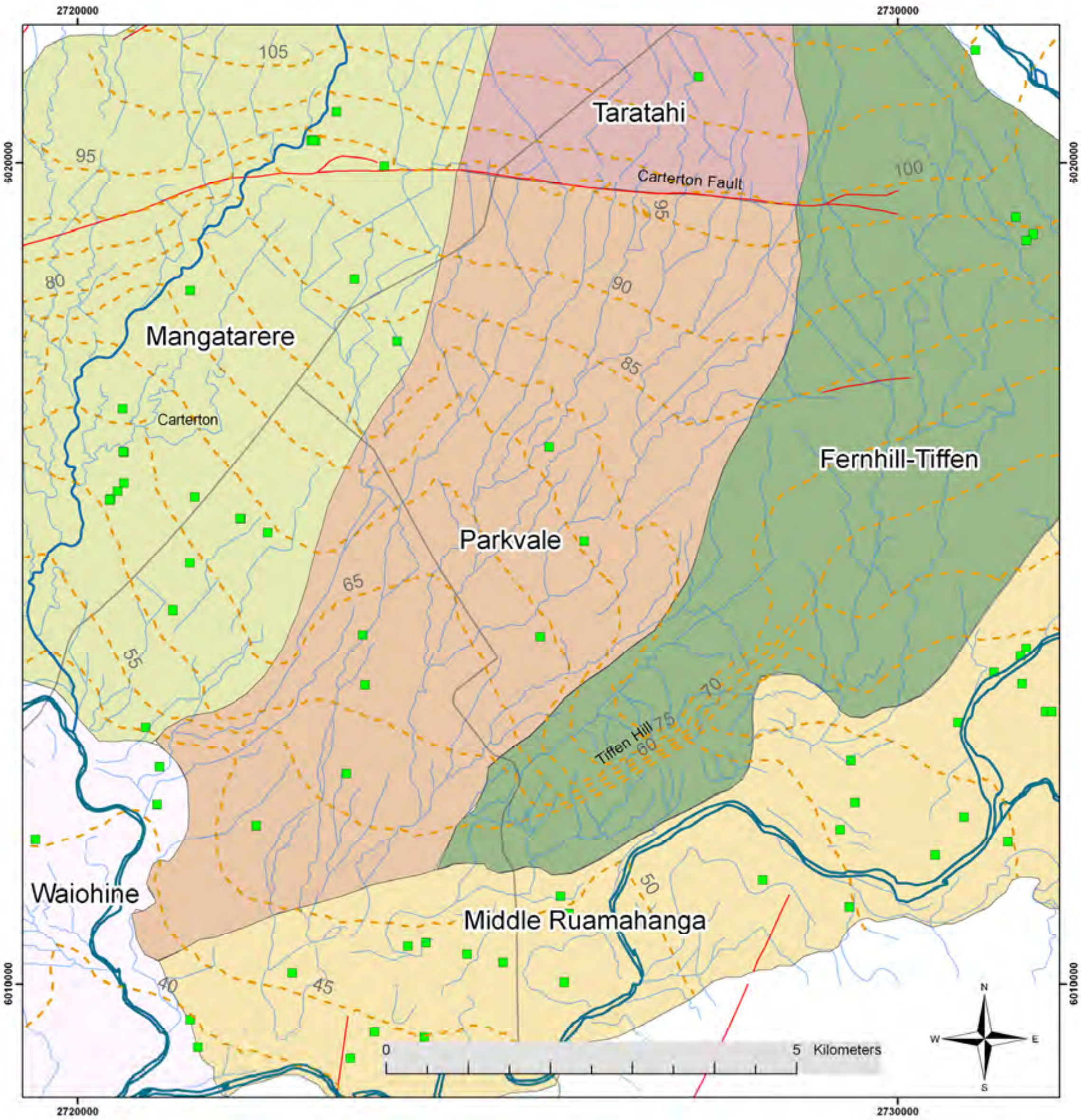

Figure E21: The Parkvale water management zone map showing existing groundwater bores with consented abstraction (green squares) and simulated groundwater flow contours (brown dashed lines at 5 m intervals in metres above mean sea level)

Area:	37.4 km^2.
Boundaries:	The western boundary is coincident with a geological fold/fault structure ('Brickworks anticline') which clearly delimits the confined Parkvale aquifers. The eastern side of the zone follows the edge of the 'Fernhill-Tiffen block' and is both a geological and hydraulic (divide) boundary. The northern boundary traces the Carterton Fault; modelling indicates this feature is likely to form a partial hydraulic boundary. The southern zone boundary follows the edge of the Q1 deposits of the Waiohine zone and cuts across to the end of Tiffen hill in an area where the aquifer sequence thins over an anticlinal structure. There is groundwater throughflow from the Parkvale zone into the Middle Ruamahanga zone.
Principal surface water systems:	Parkvale Stream, Booths Creek, Carterton Fault springs.
Aquifer sequences:	Shallow unconfined aquifer to 10-15 m depth, confined aquifers (Q6 and Q8).
Recharge:	Estimated average annual rainfall recharge (to the unconfined aquifer) is 6.76 x 10^6 m^3.
Existing RFP zones:	Parkvale (shallow and deep aquifers). Existing groundwater allocation from each of these zones is shown in Table E6.

Table E6: 'Safe yield' estimates and groundwater allocation status for existing RFP groundwater zones (WRC 1999) located in (or partially within) in the Parkvale water management zone

Existing RFP zone	RFP 'safe yield' (m^3/year)	Current allocation		% allocated
		(m^3/day)	(m^3/year)	
Parkvale ('shallow aquifers')	3.5 x 10^6	6,178	1.05 x 10^6	30
Parkvale ('deep aquifers')	2.62 x 10^6	16,782	2.613 x 10^6	100
Total	6.12 x 10^6	22,960	4.539 x 10^6	

E.6.2 Current abstraction from the Parkvale water management zone

There are only seven bores with consented abstraction located within the new Parkvale water management zone (compared to the 14 located in the existing Parkvale zone). The locations of these bores are shown on Figure E21 and all but one are screened in the confined aquifers. As at June 2010, the total consented abstraction from the zone totals approximately 14,000 m^3/day. It is estimated that actual peak daily usage is 60 to 70% of the maximum consented volume (although seasonal use may be less than 40% of the total allocated volume).

E.6.3 Hydrogeology summary

The Parkvale management zone boundaries coincide with the limits of the 'Parkvale sub-basin' which occupies a synclinal structure to a depth of about 45 to 50 m. The syncline is bordered to the west by a steep, fault-bounded anticlinal structure (known as the 'Brickworks anticline') which separates the Parkvale sub-basin from the adjacent Carterton sub-basin in the Mangatarere zone. Along the eastern edge of the sub-basin against Tiffen hill, the aquifer sequences are disrupted by a complex fault system. The Parkvale sub-basin broadens and shallows to the north and merges with alluvial fan deposits which extend into the Taratahi zone across the Carterton Fault.

Several confined gravel aquifer zones occur within the Parkvale sub-basin beneath a clay/silt aquitard (of interglacial Q5 age). The deeper confined aquifers appear to exhibit some degree of hydraulic connection (leakage) with the uppermost one (Q6 age; 20 to 30 m deep), the most productive within which the majority of bores are screened. The confined aquifers are heavily utilised for irrigation supply and exhibit a large seasonal abstraction-related drawdown of about 3 to 4 m across the sub-basin. The distinct layering of the aquitard/aquifer sequence in the Carterton area dissipates to the north as the sedimentary sequence merges with the (Waingawa) fan system.

A heterogeneous unconfined aquifer is present throughout the Parkvale water management zone extending to a depth of between 10 to 15 m below ground. This aquifer has relatively low hydraulic conductivity and variable, but generally poor, resource potential. In the northern part of the zone the deposits are part of the Waingawa alluvial fan sequence and transmit rainfall recharge to the Parkvale sub-basin confined aquifers. The unconfined aquifer also sustains baseflow to the Parkvale Stream and Booths Creek. All aquifers in the Parkvale water management zone ultimately discharge to the Waiohine and Ruamahanga river systems as shown by the potentiometric contours on Figure E21. However, the confined aquifers are regarded to have limited direct connectivity to the surface water environment.

The groundwater (and surface water) flow system of the Parkvale water management zone extends 'up-valley' into the Taratahi zone. The Taratahi zone therefore forms part of the recharge area to the Parkvale zone although throughflow across the major faults is attenuated by geological dislocation along these structures. Subdivision of the flow system along the Carterton Fault is justified both by the apparent flow attenuation across this structure and by the results of numerical modelling which indicate that drawdowns resulting from abstraction in the Parkvale water management zone are unlikely to propogate past the Carterton Fault.

E.6.4 Hydrology

Groundwater discharge in the Parkvale zone occurs into the complex drainage system of the Parkvale Stream and Booths Creek. The Taratahi Water Race also feeds water into the natural spring-fed stream system at various points rendering it difficult to quantify the overall groundwater baseflow component. Flow has been continuously monitored in the Parkvale Stream since January 2002 and the 7-day mean annual flow for the stream is estimated to be 140 L/s, and 80 L/s for Booths Creek using less reliable data (Keenan 2009). These low flow estimates include water race inflows.

Groundwater also discharges along the northern side of the Carterton Fault into a number of major spring-fed atreams and wetlands which are also interlinked with the

Taratahi Water Race system. Butcher (2007) provisionally assessed the mean spring discharge along the Carterton Fault at approximately 230 L/s.

E.6.5 Zone management objectives

The principal management objective for groundwater allocation in the Parkvale zone is to ensure the sustainable use of groundwater resources, specifically with regard to:

- protecting the instream values of hydraulically connected surface water ecosystems. This means preventing excessive baseflow depletion in the Parkvale Stream, Booths Creek and other spring-fed streams – these are the primary surface water bodies with direct connection to the groundwater environment
- preventing excessive drawdown on existing groundwater users (in the confined aquifer systems)

E.6.6 Numerical modelling

Baseline (no-abstraction) water balance

The numerical groundwater flow model (Gyopari and McAlister 2010b) was used to quantify the natural water balance for the Parkvale zone by running the model for a period of 15 years (1992 to 2007) with no groundwater abstraction occurring. This scenario provides a baseline simulation against which the effects of various abstraction scenarios can be evaluated. Of particular relevance to assessing the sustainability of abstraction, the model provides information on the cumulative depletion effects of groundwater pumping on the surface water environment. Groundwater abstraction from the Parkvale zone can potentially result in depletion of several connected surface water environments:

- Parkvale and Booths Creeks springs
- Ruamahanga River
- Waiohine River

Although the rivers lie outside the bounds of the zone, they potentially receive throughflow discharge from the Parkvale zone.

The Carterton Fault springs are not included since they largely occur on the northern side of the fault and modelling has shown that they are unlikely to be affected by groundwater abstraction from the Parkvale water management zone and are most sensitive to Taratahi zone abstraction.

The principal water balance components for the Parkvale zone are rainfall recharge and groundwater discharge to surface water. Figure E22 shows the modelled annual rainfall recharge for the Parkvale zone for the period 1992 to 2006. The average annual rainfall recharge for this period is 6.76×10^6 m^3 and the lower quartile annual rainfall is 3.87×10^6 m^3.

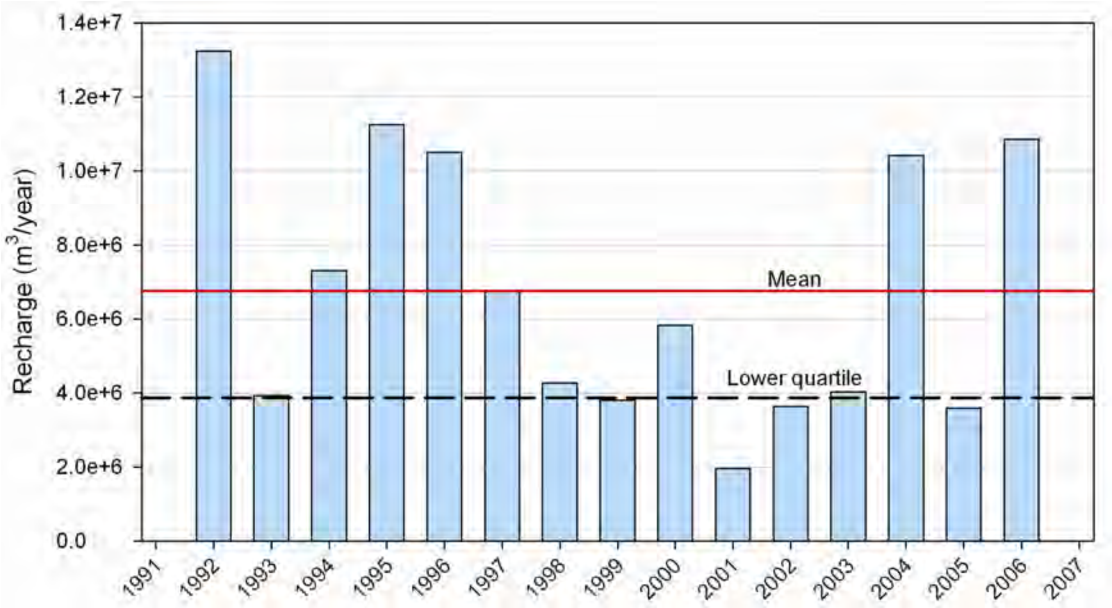

Figure E22: Modelled annual rainfall recharge 1992–2006 for the Parkvale zone in the Middle Valley (mean annual recharge is 6.76 x 10^6 m^3 and the lower quartile annual rainfall is 3.87 x 10^6 m^3)

Figure E23 shows the total simulated groundwater discharge to surface water in the Parkvale zone (to the Parkvale Stream and Booths Creek systems). The 7-day MALF for the springs is estimated to be 220 L/s (Keenan 2009) – this is shown by the red line on Figure E23 and is clearly much greater than the modelled low flow for the springs of about 70 L/s (shown by the blue line). The discrepancy is related to a contribution to the flow in the Parkvale Stream by the Taratahi Water Race which is indicated by the groundwater modelling to contribute about two-thirds of the total stream flow.

The natural throughflow from the Parkvale zone to the Middle Ruamahanga and Waiohine zones is shown in Figure E24. The long-term throughflow rates appear to largely reflect temporal climate variability. The model simulations suggest there is significantly higher throughflow to the Middle Ruamahanga zone which recedes to a summer rate of about 11,000 m^3/day (127 L/s) compared to throughflow into the Waiohine zone which totals approximately 5,000 m^3/day during summer (58 L/s). Given the potential magnitude of this cross-boundary flux any reduction in throughflow from the Parkvale zone to the Middle Ruamahanga zone should be taken into consideration in the allocation of water resources in both zones.

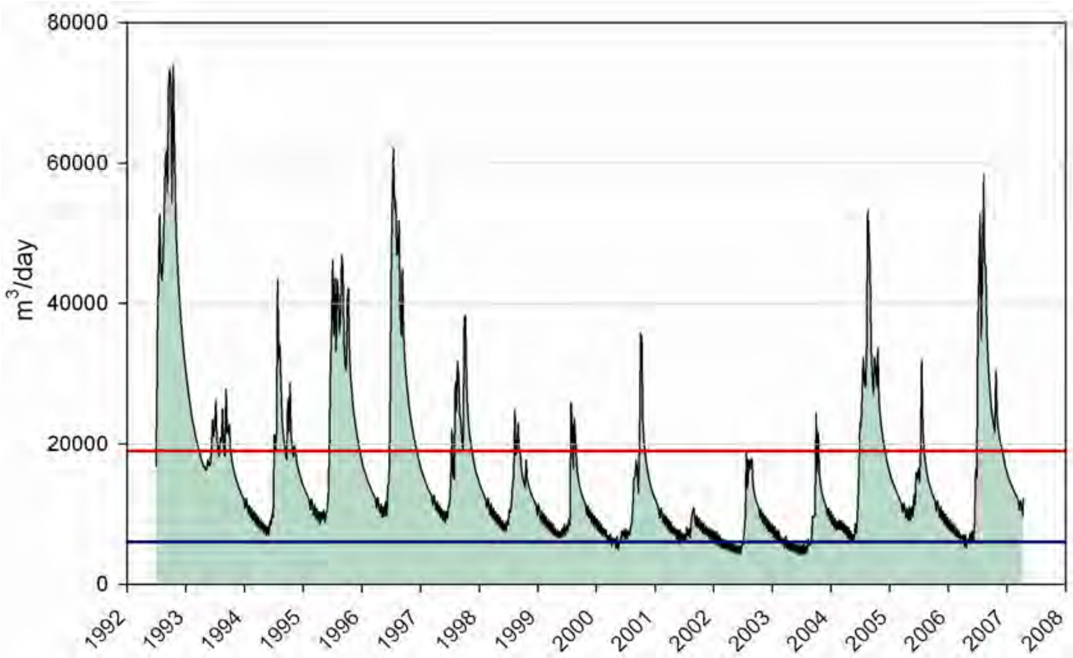

Figure E23: Simulated groundwater discharge to surface water for the Parkvale zone when there is no groundwater abstraction for the period 1992–2007. The red line corresponds to the 7-day MALF for the Parkvale Stream and Booths Creeks of 220 L/s as estimated by Keenan (2009). The blue line represents the modelled summer baseflow for these streams (70 L/s). The discrepancy is inferred to reflect (at least in part) the inflow contribution from the Taratahi Water Race which artificially elevates the MALF calculated from flow gauging data.

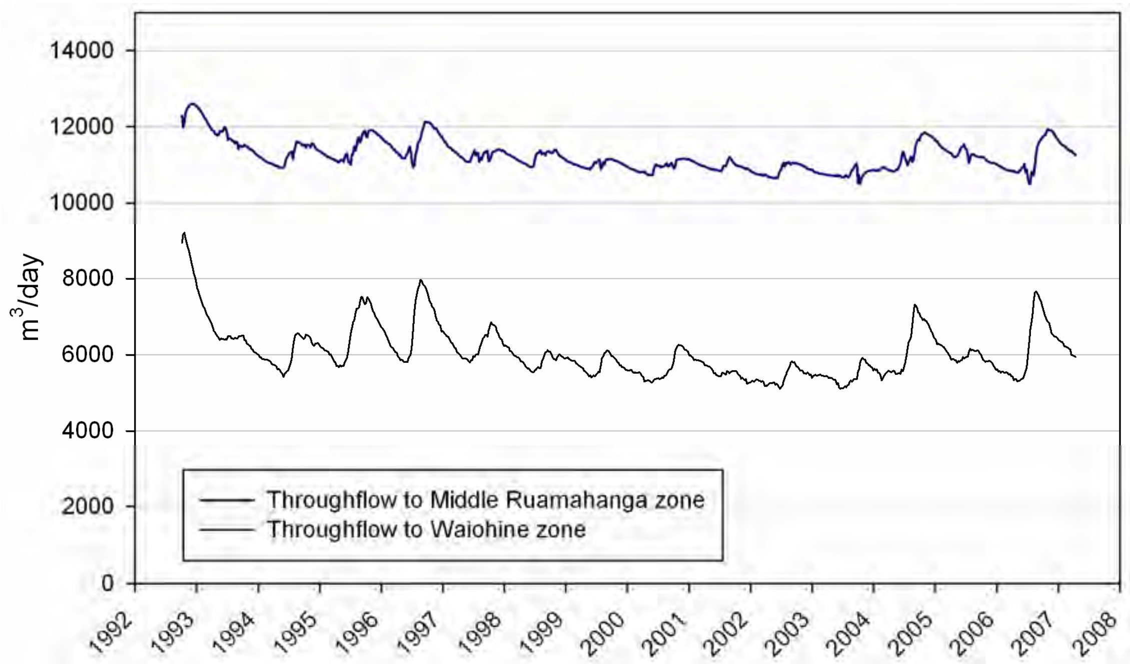

Figure E24: Simulated groundwater throughflow from the Parkvale zone into the Middle Ruamahanga and Waiohine zones for the period 1992–2007 (no-abstraction scenario)

Modelled abstraction effects 1992-2007

Groundwater abstraction was simulated for the 15-year transient model run and is shown in Figure E25. It is noted that virtually all abstraction in the Parkvale water management zone is derived from the Q6 confined aquifer. Seasonal abstraction increases significantly over the simulation period and now peaks at an estimated 8,000 m^3/day (modelled actual abstraction) or approximately 60% of the current allocation of approximately 14,000 m^3/day.

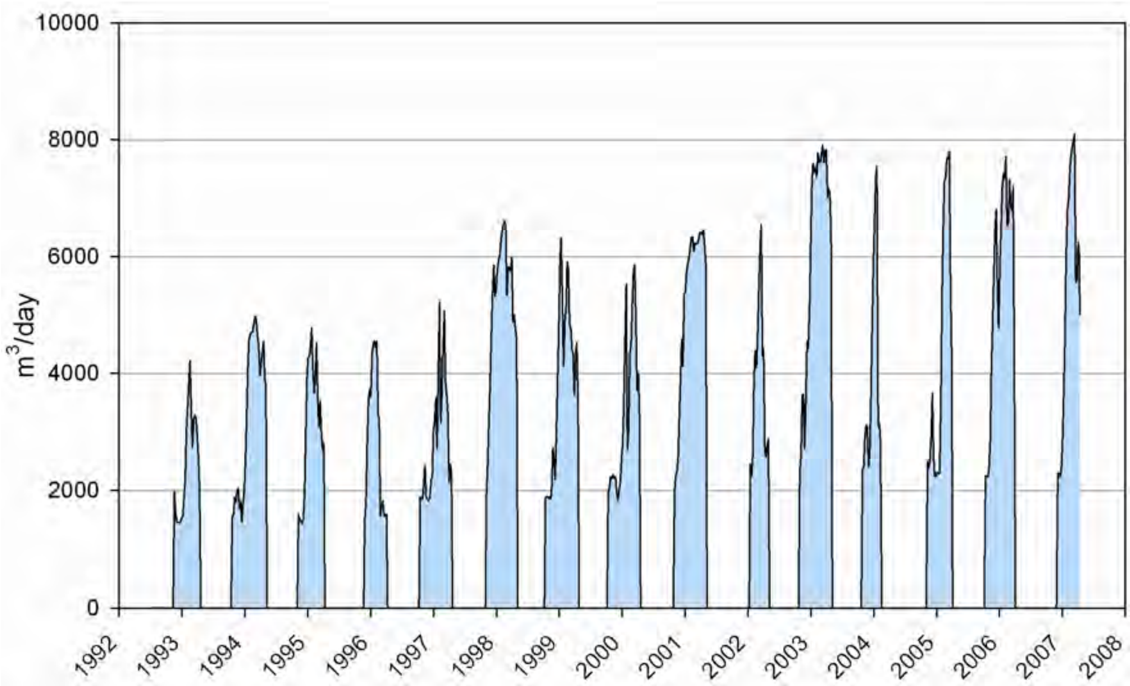

Figure E25: Simulated historic abstraction in the Parkvale zone between 1992 and 2007. Most of the abstraction occurs from the Q6 aquifer in the Parkvale sub-basin.

Figure E26A shows the simulated surface water depletion in the Parkvale zone resulting from historical abstraction. Potential surface water depletion effects were calculated by comparing the baseline non-pumping simulation with the historical abstraction simulation. The groundwater model predicts that current peak seasonal spring flow depletion is approximately 2,200 m^3/day (25 L/s) or about 28% of the abstraction rate. Figure E26B illustrates that seasonal surface water depletion peaks towards the end of each irrigation season, but does not cease when pumping is switched off; rather there is a considerable lag shown by the slowly receding depletion into the winter months. During wet years when rainfall recharge is above average, aquifer storage is replenished more quickly and the depletion rate reduces more rapidly. Therefore, regulation of pumping in deeper confined aquifers is unlikely to provide a means to control or mitigate potential surface water depletion effects due to the system lag and the necessity for storage to be replenished by winter recharge.

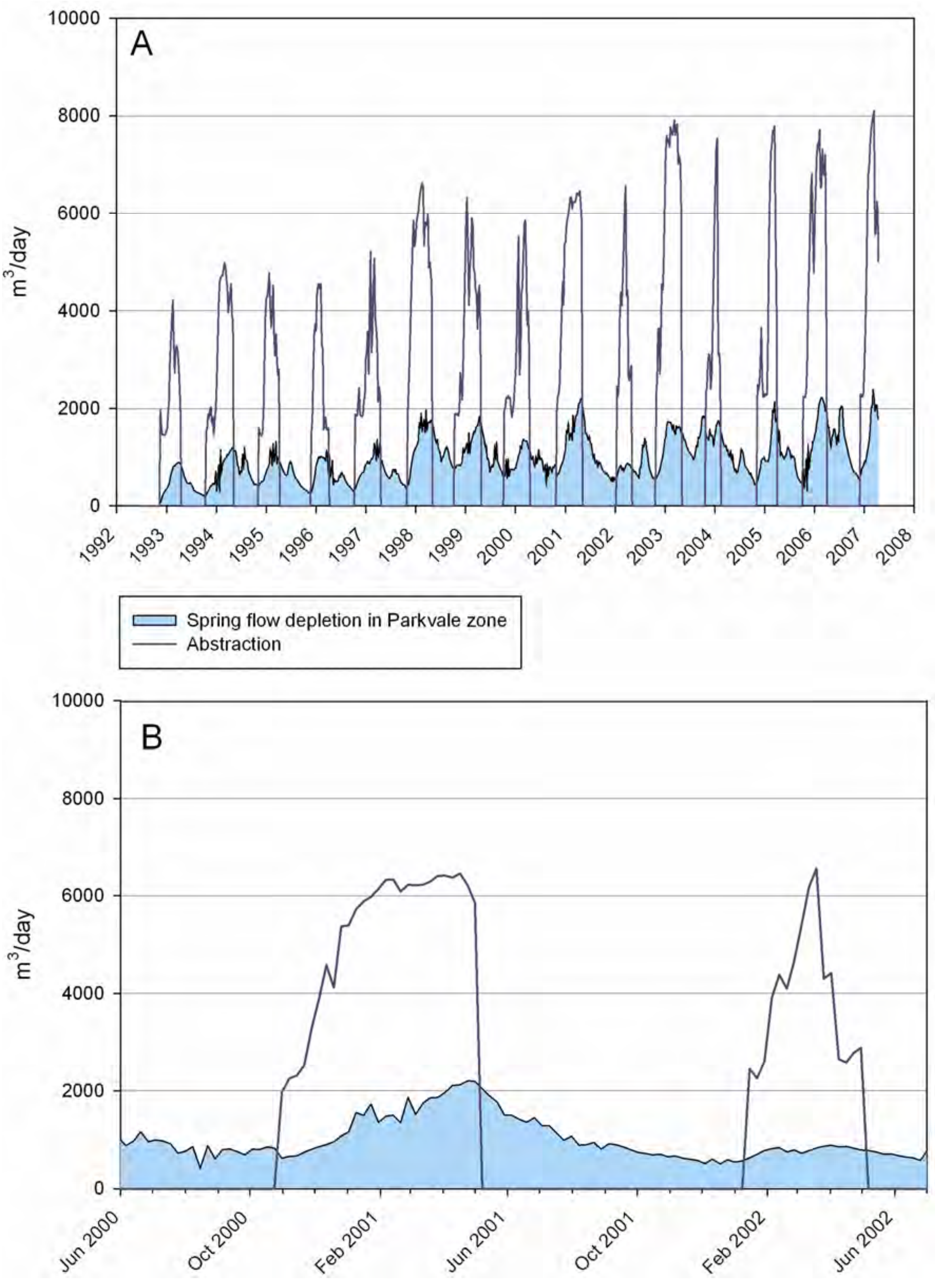

Figure E26: Simulated spring flow depletion resulting from existing groundwater abstraction in the Parkvale zone. A: full model run and B: June 2000 to June 2002 detailed depletion plots.

The groundwater model was also used to assess the throughflow reduction to the Middle Ruamahanga zone when pumping is occurring from both zones. Figure E27 shows the simulated throughflow depletion over the model calibration period which reaches approximately 1,000 m^3/day (11.5 L/s) during the final 5 years of the model run. This is equivalent to about 12% of cumulative pumping from the Parkvale zone and about 10% of the natural throughflow rate (see Figure E24). The reduction in throughflow input to the Middle Ruamahanga water management zone is therefore potentially significant should abstraction rates increase in the confined Parkvale aquifers.

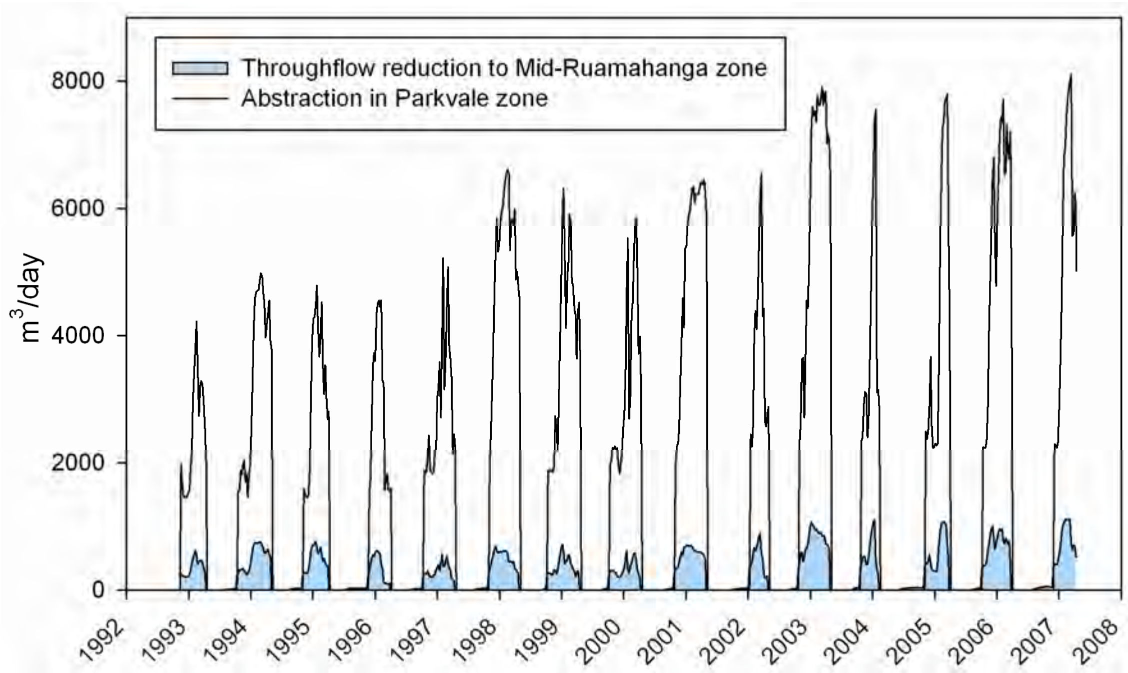

Figure E27: Simulated reduction in throughflow to the Middle Ruamahanga water management zone as a result of abstraction from the Parkvale zone. The depletion is equivalent to about 12% of the Parkvale pumping rate and was about 10% of the natural throughflow rate in 2006/07.

E.6.7 Abstraction scenarios

The transient groundwater flow model for the Middle Valley catchment was used to simulate 'synthetic' abstraction scenarios to further characterise the relationship between groundwater abstraction at different levels in the aquifer system and surface water depletion. The transient model run time was shortened to just over 18 months (2 May 2000 to 27 November 2001; model days 2,863 to 3,473) – spanning an average recharge year (2000) and a very dry year (2001).

The following abstraction scenarios were simulated:

Scenario 1: Abstraction from the unconfined aquifer only at a rate of 12,000 to 13,000 m^3/day from a distributed array of 52 bores each pumping at 250 m^3/day. The bores were assigned to models slices 4 and 5 (refer to Gyopari and McAlister 2010b for more detail). Pumping rate was held constant over a 154 day pumping period (Nov-Apr).

Scenario 2: Abstraction from the confined (Q6) Parkvale sub-basin aquifers only at a rate of 10,500 m^3/day for a period of 154 days (Nov-Apr). The abstraction was distributed evenly between ten bores assigned to model slice 8.

Scenario 3: As for Scenario 2 except the total abstraction rate was increased to 15,000 m^3/day.

Figure E28 shows the results of Scenario 1 in terms of surface water depletion effects. The plot shows that when the unconfined aquifer only is pumped, the largest depletion effect occurs in the Parkvale springs (in the order of 30% of the pumping rate). The Ruamahanga River shows a small depletion of about 10 to 15% of the pumping rate while the Waiohine River shows a much smaller depletion of 5 to 6%. There is virtually no effect on the Carterton Fault springs.

Results of this scenario suggest stream depletion effects from pumping in the unconfined aquifer are likely to result in relatively indirect effects (i.e. q/Q <0.5) except where abstraction occurs in the immediate vicinity of a spring-fed stream. As a consequence, it is recommended that the unconfined aquifer in the Parkvale water management zone be classified as in terms of Category B (high) hydraulic connection. This would mean groundwater takes are managed solely in terms of groundwater allocation except when they are located sufficiently close to an individual spring-fed stream to result in significant stream depletion effects that can be mitigated by pumping regulation.

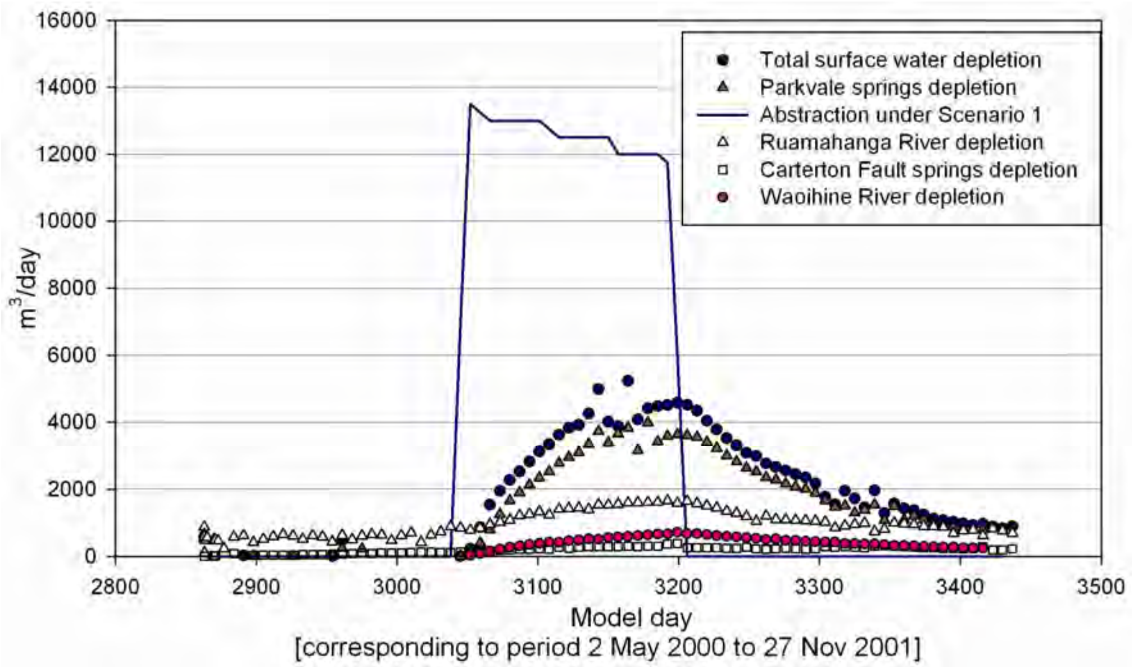

Figure E28: Scenario 1 output – surface water depletion resulting from groundwater abstraction from the unconfined aquifer in the Parkvale zone over one irrigation season (2000-01)

The surface water depletion effects resulting from Scenario 1 abstraction is also represented in Figure E29 as the ratio between depletion rate (q) and pumping rate (Q). This plot shows that the depletion factor (q/Q) is approximately 0.3 for the total depletion effects in the zone (associated predominantly with effects in the Parkvale Stream and Booths Creek system).

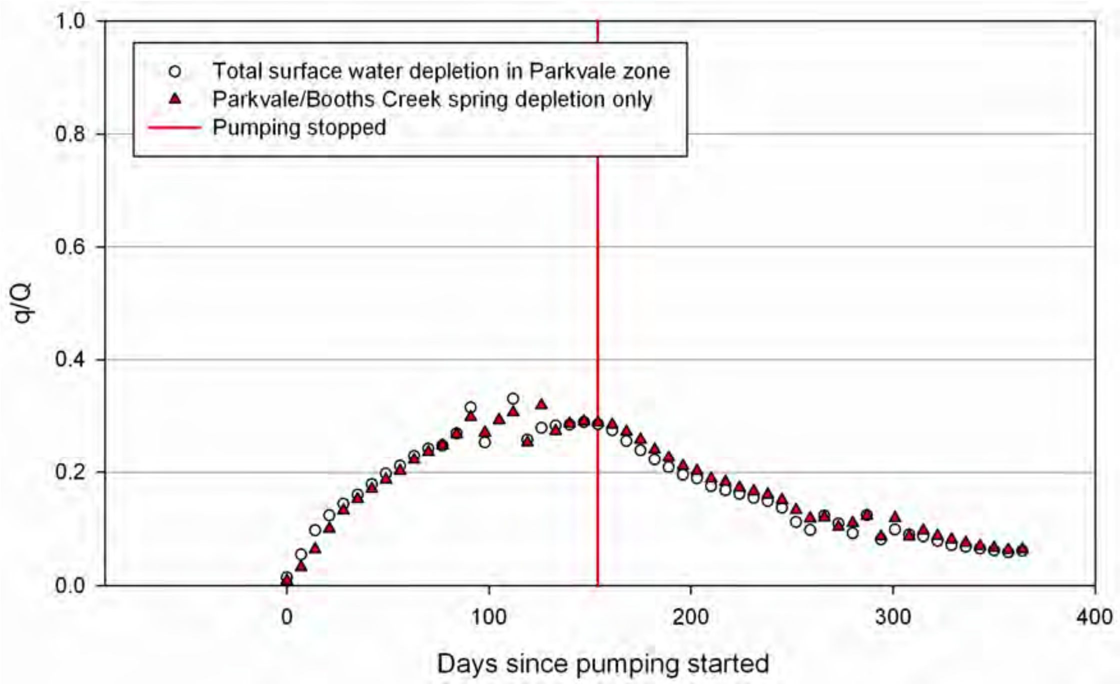

Figure E29: Scenario 1 output – surface water depletion resulting from groundwater abstraction from the unconfined aquifer in the Parkvale zone expressed as the ratio of depletion rate (q) and pumping rate (Q)

The results from abstraction Scenario 2 are shown in Figure E30. As expected, when abstraction occurs only from the confined aquifer (Q6) the surface water depletion effects are smaller than when pumping occurs from the unconfined aquifer. The plot shows that after 154 days of pumping, the spring depletion is equivalent to about 25% of the abstraction rate (i.e q/Q = 0.25). Depletion effects on the Waiohine and Ruamahanga rivers are relatively small (q/Q = 0.07 and 0.04 respectively), and negligible for the Carterton Fault springs.

The drawdown magnitude in the confined Q6 Parkvale aquifer is also an important management consideration. Figure E31 shows the simulated drawdown at the end of the pumping period on model slice 8 (Q6 confined aquifer) along a transect line (see Figure E32) starting at the Ruamahanga River in the south (distance = 0 m) and ending north of the Carterton Fault. Two pumping rates are shown, 10,500 m^3/day (open circles) and 15,000 m^3/day (red circles). Simulated drawdown progressively increases from a negligible amount at the Ruamahanga River, to between 3 and about 5 m in the central part of the sub-basin (depending on the pumping rate), and reduces to near zero around the Carterton Fault. Also shown on Figure E31 is a shorter transect between the Waiohine River and the Parkvale sub-basin for the Q6 confined aquifer (slice 8), and drawdown on slice 4 (unconfined aquifer).

The drawdown predicted in the Q6 confined aquifer of about 4.5 m at a pumping rate of 15,000 m^3/day suggests that the sub-basin confined aquifers could not sustain a significantly higher abstraction rate without causing adverse effects on groundwater users. It is suggested that a maximum drawdown of 5 to 6m should be maintained. The current seasonal drawdown in this aquifer is approximately 3 to 4 m at an estimated pumping rate of 8,000 m^3/day (see Figure E25) although this could be underestimated as Figure E31 suggests that such a drawdown would occur at a daily pumping rate of 10,000 m^3/day.

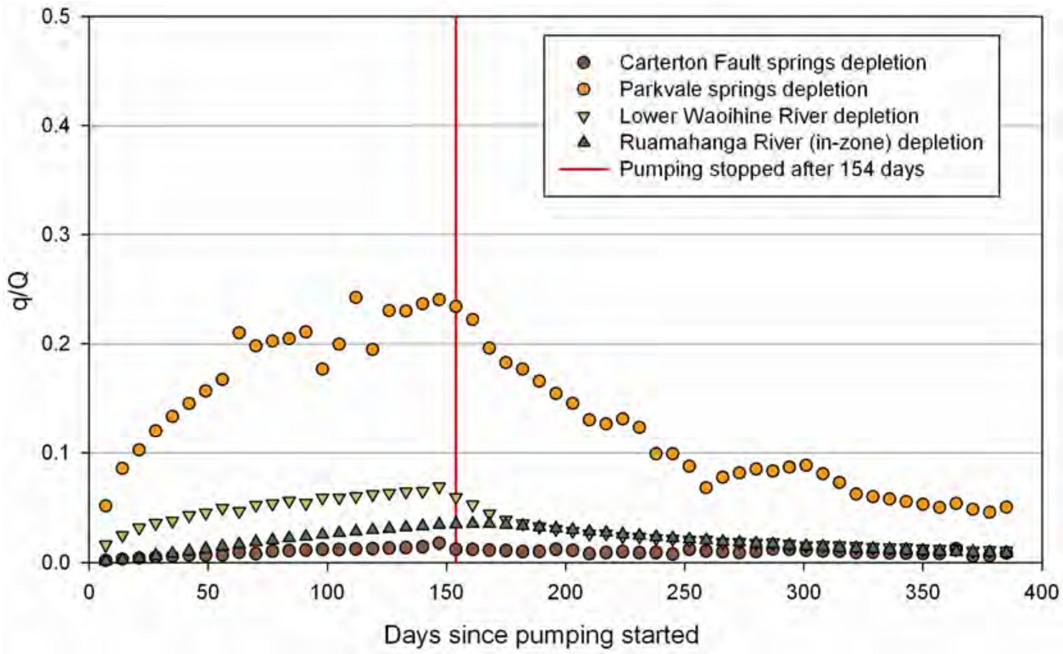

Figure E30: Scenario 2 output – surface water depletion resulting from groundwater abstraction from the confined Q6 aquifer in the Parkvale zone expressed as a 'depletion factor' – the ratio of depletion rate (q) and pumping rate (Q)

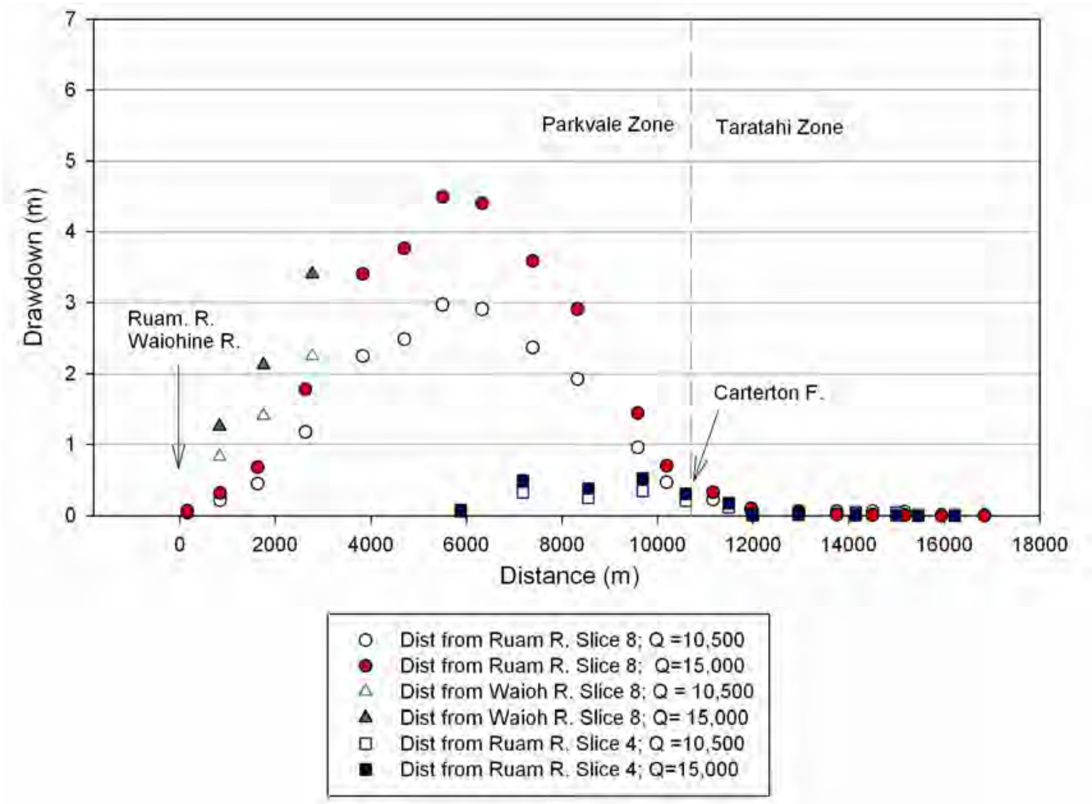

Figure E31: Scenarios 2 and 3 outputs – simulated drawdowns after 154 days pumping at 10,500 and 15,000 m^3/day along a transect through the Parkvale zone from the Ruamahanga River (distance = 0 m) to north of Masterton Fault in the Taratahi zone. See Figure E32 for transect location. Slice 8 = Q6 confined aquifer; Slice 4 = Q2 unconfined aquifer.

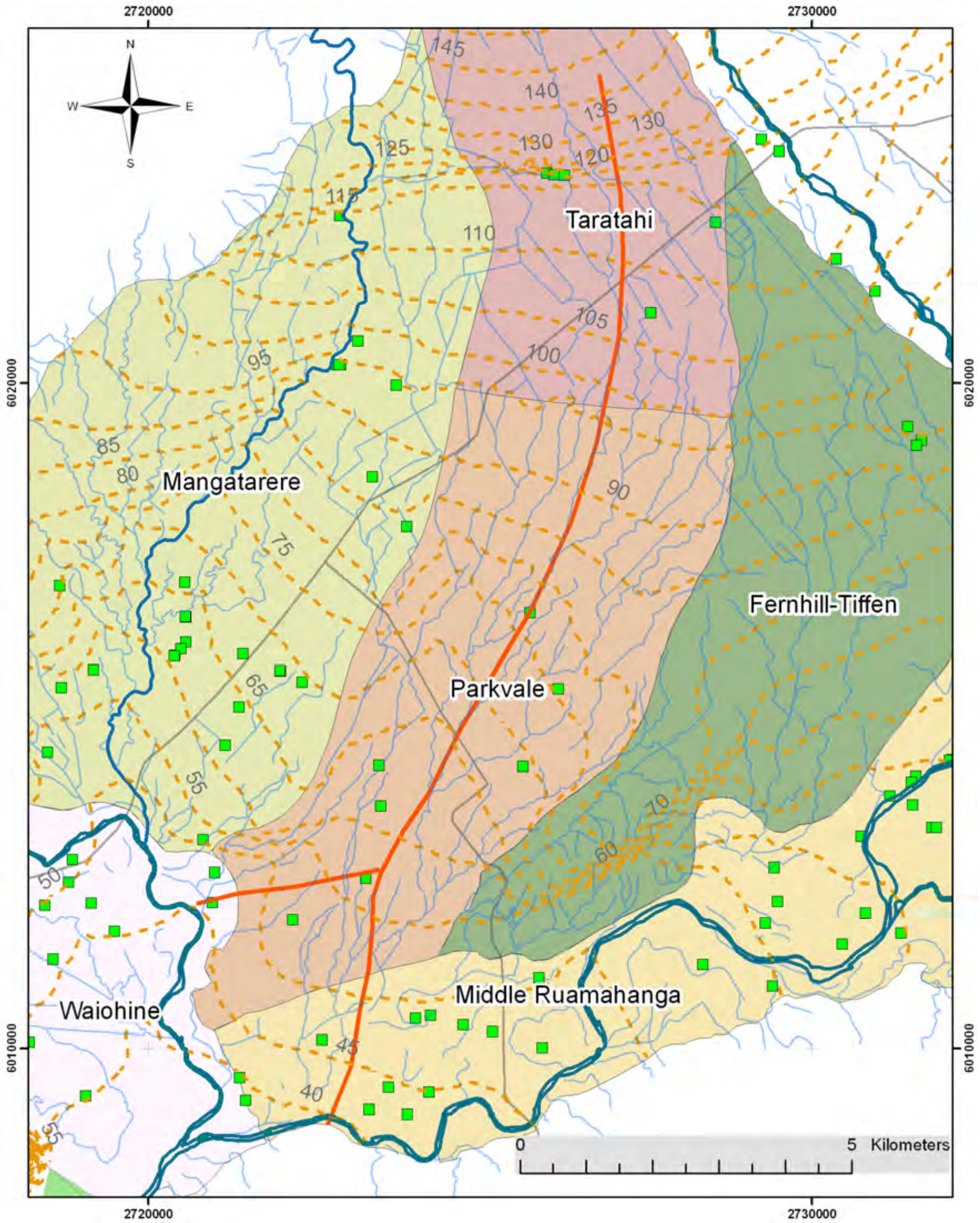

Figure E32: Transect lines (in red) used for presenting simulated aquifer drawdown characteristics across the Parkvale basin as shown in Figure E31

E.6.8 Groundwater management options for the Parkvale water management zone

Groundwater-surface water interaction zones

- The shallow unconfined/semi-confined groundwater system across the entire Parkvale water management zone should assigned Category B status to a depth of 20 m. This recognises the numerous spring-fed streams in this zone and the sensitivity of these to nearby shallow abstraction.

- The confined aquifers below 20 m depth should be classified as Category C to reflect their low to moderate connectivity to surface water.

Groundwater allocation

- The confined and unconfined aquifers in the Parkvale zone should be managed separately.

- Allocation management options should be based upon the management of surface water depletion effects in the Parkvale Stream/Booths Creek systems. Relating abstraction to the flow in these springs will effectively avoid any significant depletion effects on the Waiohine and Ruamahanga rivers.

- Cumulative drawdown effects in the confined aquifer should be limited to about 5 m. Modelling indicates that this drawdown would occur at a pumping rate of about 15,000 to 17,000 m^3/day.

- Surface water depletion factors[29] of 0.22 for the confined aquifer and 0.3 for the unconfined aquifer should be adopted.

- The reference surface water flow should be the mean annual discharge to the surface water environment from the Parkvale zone as predicted by the groundwater model. This is 220 L/s (19,000 m^3/day) and corresponds to the estimated 7-day MALF for the Parkvale Stream and Booths Creek.

- The reduction in throughflow to the Middle Ruamahanga zone should be accounted for in the allocation scheme for that zone using the following relationship:

*Parkvale (confined) zone allocation * 0.12*

Potential options for unregulated groundwater abstraction (i.e. Category B/C) in the Parkvale water management zone are outlined in Table E7.

For the confined aquifer, Option 1 is recommended which equates to a MALF depletion of 10% in the Parkvale Stream and Booths Creek (note: the unconfined aquifer allocation and surface water/Category A allocation will compound the MALF depletion). These are already highly allocated streams with respect to surface water and Category A allocation so therefore additional depletion is not recommended. Under this option, the total depletion contribution on the Ruamahanga River is about 0.5%.

For the unconfined Parkvale aquifer, Option 1 is recommended which equates to a further 3% further depletion in MALF for the streams (total depletion from groundwater allocation alone would therefore be 23% when the confined aquifer allocation is added).

Together, allocation from the confined and unconfined aquifers is equivalent to about 50% of the LSR (lower quartile) – in excess of the 20-30% guide. It is not recommended that the total allocation exceeds 50% of LSR (mean annual).

29 Depletion factor = fraction of pumping rate which contributes to surface water depletion. Obtained from model scenarios.

Table E7: Allocation options for the confined and unconfined aquifers in the Parkvale water management zone

Option	Cumulative depletion effect on mean groundwater discharge	Allocation* (m^3/day)	Allocation** (m^3/year x 10^6)	% LSR***
Confined aquifer				
1	10% depletion	8,636	1.55	40
2	15% depletion	12,960	2.33	60
3	20% depletion	17,280	3.11	80
Unconfined aquifer				
1	3% depletion	1,900	0.342	9
2	5% depletion	3,166	0.57	15
3	10% depletion	6,336	1.14	29
4	15% depletion	9,504	1.71	44

*Daily allocation is calculated by dividing the percentage of MALF by the depletion factor, q/Q (as derived from the groundwater model).

** Annual allocation limit is based on pumping for 180 days per year.

***LSR = lower quartile annual land surface recharge (for reference only). Note LSR for the confined aquifer is the sum of half the mean annual recharge for the Parkvale zone + Taratahi zone recharge. This is because the recharge area for the confined Parkvale aquifers is regarded to extend between the upstream half of the Parkvale zone and into the Taratahi zone. This is 8.08 x $10^6 m^3$/year. LSR for unconfined aquifer is Parkvale zone mean annual recharge only (6.76 x $10^6 m^3$/year).

E.7 Taratahi water management zone

E.7.1 Overview

Delineation: The Taratahi water management zone is coincident with the northern portion of the elongate Parkvale-Taratahi drainage system occupying the central part of the Middle Valley catchment (Figure E33).

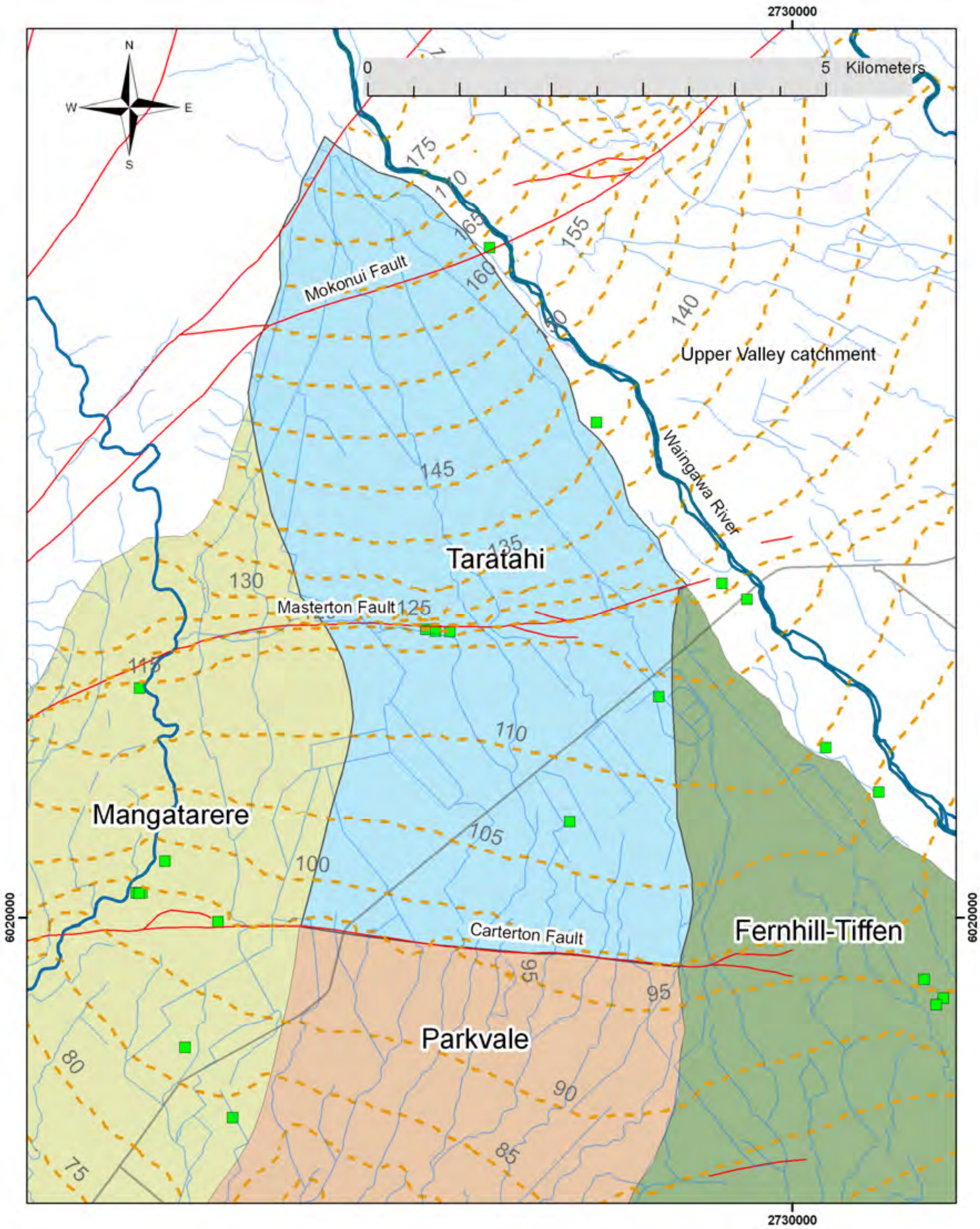

Figure E33: The Taratahi water management zone map showing existing groundwater bores with consented abstraction (green squares) and groundwater flow contours (brown dashed lines at 5 m intervals).

Area: 29.32 km^2.

Zone boundaries: The western boundary follows a groundwater divide between the Taratahi and Mangatarere zones. The eastern limit is coincident with the edge of the 'Fernhill block' and is both a geological and hydraulic (divide) boundary.

The southern boundary is defined by the Carterton Fault which forms a partial hydraulic boundary. Modelling work shows that abstraction effects within the bounding Parkvale water management zone to the south do not extend across the fault.

The northern edge of the zone corresponds to the Waingawa River Q2 terrace edge which represents both a geological and hydraulic boundary.

Principal surface water systems: Springs associated with the Masterton and Carterton faults.

Aquifer sequences: A single leaky heterogeneous system of generally low permeability and limited groundwater resource potential.

Recharge: The average annual rainfall recharge for the zone is 11.1 x 10^6 m^3.

Existing RFP zones: East and West Taratahi. Existing groundwater allocation from each of these zones is shown in Table E8.

Table E8: 'Safe yield' estimates and groundwater allocation status for existing RFP groundwater zones (WRC 1999) located within the Taratahi water management zone

Existing RFP zone	'Safe yield' (m^3/year)	Current allocation		% allocated
		(m^3/day)	(m^3/year)	
East Taratahi	6.8 x 10^6	1,165	0.228 x 10^6	3
West Taratahi	5.3 x 10^6	7,906	0.648 x 10^6	12
Total	12.1 x 10^6	9,071	0.876 x 10^6	

E.7.2 Current consented groundwater abstraction from the Taratahi zone

As at June 2010, there are currently only six consented groundwater takes in the Taratahi water management zone; these bores have a combined allocation of 5,300 m^3/day. The bore locations are shown on Figure E33.

E.7.3 Hydrogeology summary

In general, the Taratahi zone comprises a heterogeneous alluvial gravel sequence which extends to more than 50 m depth and typically exhibits low permeability and poor groundwater resource potential. There is no obvious stratification of the sequence and enhanced bore yields are possible where localised reworking of matrix-rich fan gravels has occurred. Complex structural features (such as the Carterton Fault and the Brickworks anticline/fault complex) deform the alluvial deposits and influence groundwater flow patterns.

The dominant recharge mechanism is rainfall infiltration. Groundwater baseflow discharge occurs into the linear spring-fed streams along the Masterton and Carterton faults and as throughflow into the Parkvale water management zone to the south.

E.7.4 Hydrology

Spring discharges are associated with the Masterton and Carterton faults. The fault structures have created topographic breaks and appear to impede the flow of groundwater in some areas resulting in the emergence of springs along the fault traces. There is very limited information regarding the flow rates from these springs but estimates have been made using historic spot gauging data and visual flow estimates. Three main springs occur along the Masterton Fault – the Waingawa Spring and wetland, Parkers Stream and Wiltons Drain – but diffuse spring discharges appear to occur along the entire length of the fault trace. The estimated mean spring discharge along the Masterton Fault is 120 L/s which reduces significantly during dry summer periods to about 30 L/s. Considerably more groundwater discharge occurs along the Carterton Fault from a number of major springs. The springs are interlinked by the Taratahi Water Race system making it difficult to quantify the groundwater discharge component. The mean spring flow from the Carterton Fault is estimated to be about 230 L/s.

Numerical modelling in the absence of groundwater abstraction (and water race inputs) indicates the combined (natural) mean low flow from all springs in the Taratahi zone is likely to be of the order of 100 L/s (8,640 m^3/day).

E.7.5 Zone management objective

The principal management objective for groundwater allocation in the Taratahi zone is to ensure the sustainable use of groundwater resources while protecting the instream values of hydraulically connected surface water ecosystems; preventing excessive baseflow depletion in the spring systems is of primary importance.

E.7.6 Numerical modelling

Baseline (no-abstraction) water balance

The numerical groundwater flow model (Gyopari and McAlister 2010b) was used to quantify the water balance for the Taratahi zone by running the model for a period of 15 years (1992 to 2007) with no groundwater abstraction occurring. This no-abstraction scenario was used as a baseline simulation against which the effects of various abstraction scenarios were evaluated. Of particular relevance to assessing the sustainability of abstractions, the model provides information on the depletion effects of cumulative groundwater pumping on the surface water environment.

The principal water balance components for the Taratahi water management zone are rainfall recharge and groundwater discharge to surface water. Figure E34 shows the modelled annual rainfall recharge for the Taratahi zone for the period 1992 to 2006. These calculations indicate an average annual rainfall recharge over this period of 1.1 x 10^7 m^3 and the lower quartile annual recharge is 8.13 x 10^6 m^3.. Figure E35 shows the total simulated groundwater discharge to the faultline springs within the zone. Also shown is the estimated mean annual low flow for the springs of about 9,000 m^3/day (100 L/s).

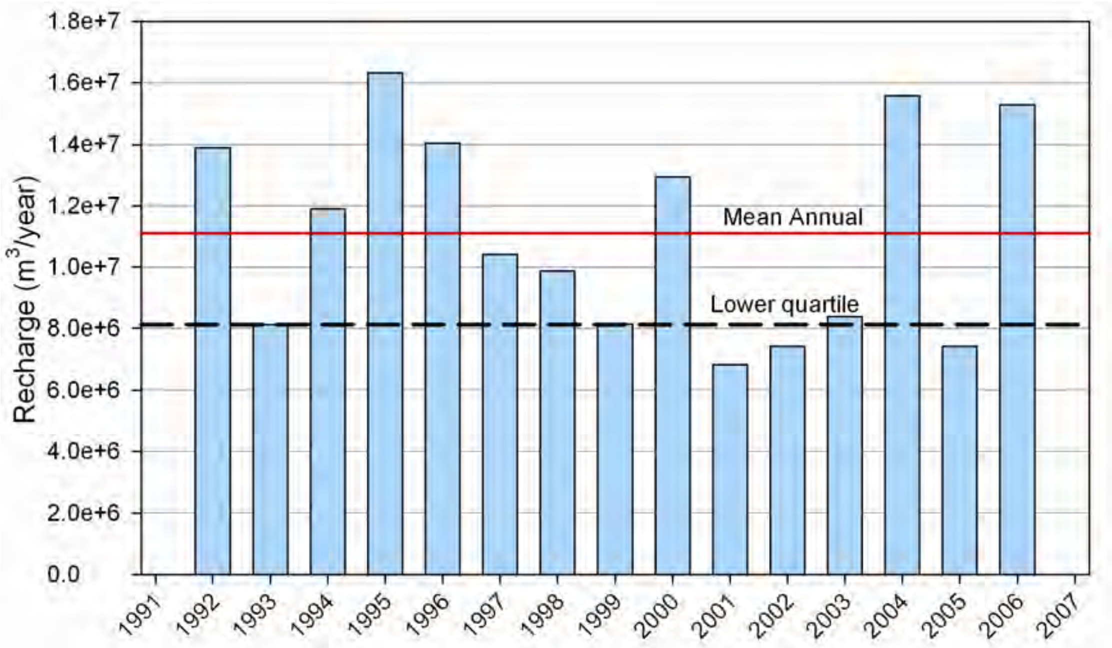

Figure E34: Modelled annual rainfall recharge (1992-2006) for the Taratahi zone (mean annual recharge is 1.1 x 10^7 m^3 and lower quartile annual recharge is 8.13 x 10^6 m^3)

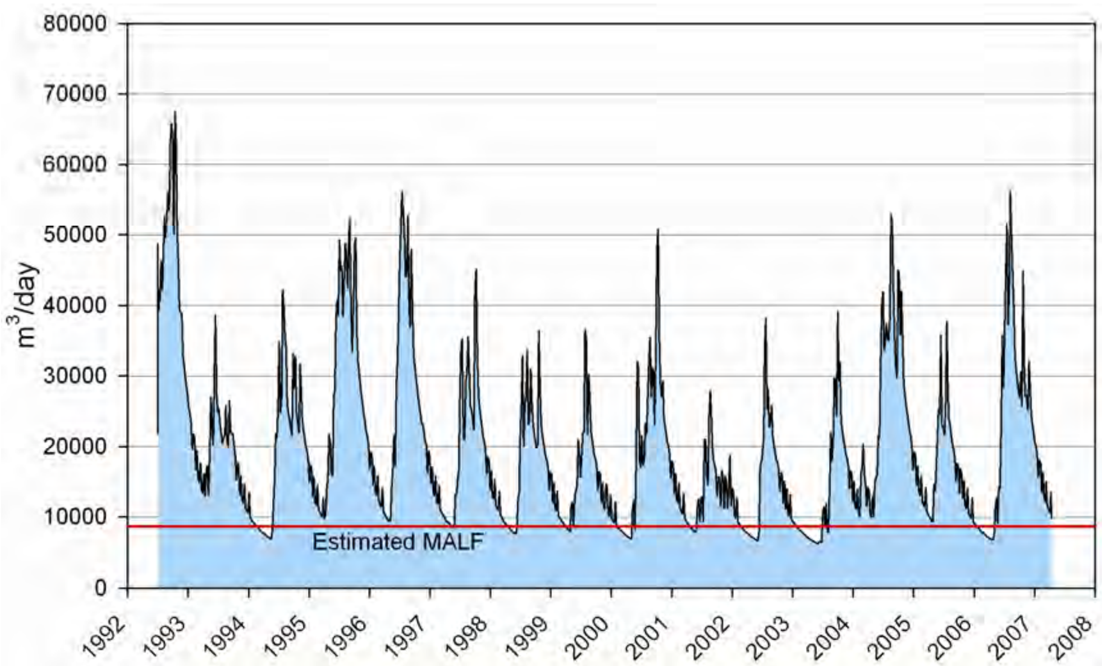

Figure E35: Simulated groundwater discharge to springs in the Taratahi zone of the Middle Valley catchment. Note the estimated mean annual low flow (MALF) is based on the model predictions in the absence of groundwater abstraction.

E.7.7 Assessment of spring-flow depletion

The transient groundwater flow model for the Middle Valley catchment was used to simulate a 'synthetic' abstraction scenario in order to characterise the relationship between groundwater abstraction and spring flow depletion. The transient model run time was shortened to just over 18 months (2 May 2000 to 27 November 2001; model days 2,863 to 3,473), selected to span an average recharge year (2000) and a very dry year (2001).

Only one scenario was simulated: synthetic distributed abstraction from the shallow aquifer (outside 500 m spring buffer zone) from numerous low-yielding bores totalling 7,300 m^3/day (24% of the daily average rainfall recharge). The pumping rate was held constant over 154 days (Nov-April). Abstraction was distributed across the zone on model slice 4 (refer to Gyopari and McAlister 2010b for details) with each bore having a pumping rate of 250 m^3/day (to avoid drying of layers due to the low hydraulic conductivity of the fan sequences).

Figure E36 shows the outputs of the scenario as the ratio between the spring depletion rate (q) and the average pumping rate (Q). The plot does not show a theoretical 'smooth' curve since there is minor instability in the model as the constrained transfer boundary nodes regulate spring flows out of the aquifer. The output nevertheless clearly shows that after 154 days of groundwater pumping, the total depletion in the zone is equivalent to about 22% of the abstraction rate. It is therefore recommended that the entire Taratahi water management zone to a depth of 20 m is managed in terms of the Category B hydraulic connectivity classification. This would allow abstraction to be managed in terms of overall groundwater allocation except where pumping was located sufficiently close to an individual surface water body to induce stream depletion effects able to be mitigated by application of pumping regulation.

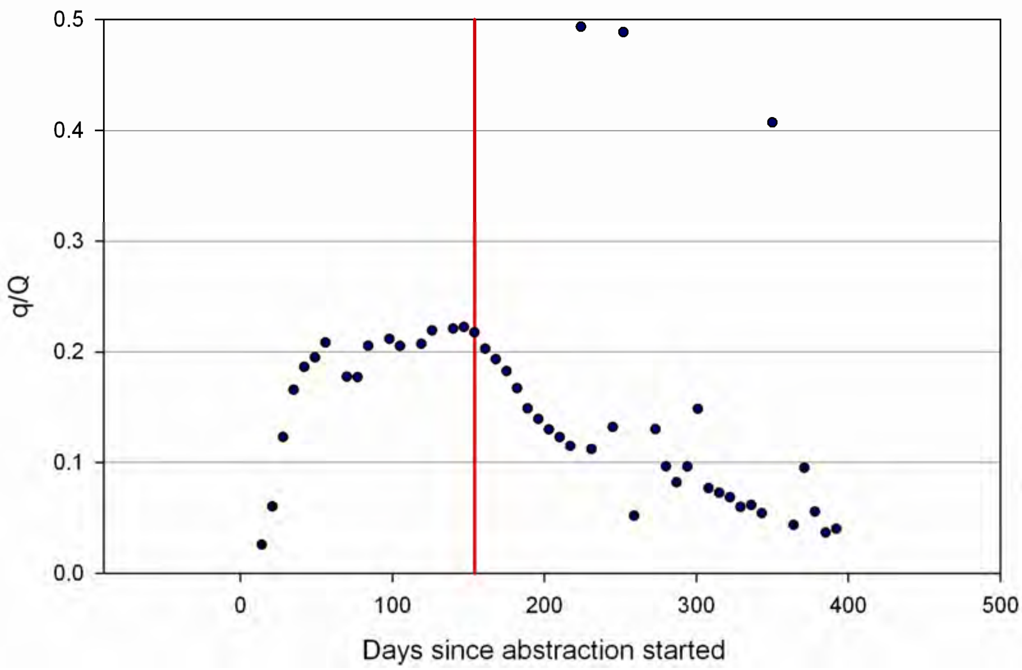

Figure E36: Ratio of spring flow depletion (q) to pumping rate (Q) for the Taratahi zone scenario resulting from the cumulative effect of shallow groundwater abstraction. The red line shows when groundwater pumping stopped at 154 days at an average rate of 7,300 m^3/day.

E.7.8 Groundwater management options for the Taratahi water management zone

Groundwater-surface water interaction zones

- The shallow unconfined/semi-confined groundwater system across the entire zone should be Category B to a depth of 20 m. This recognises the numerous spring-fed streams in this zone and the sensitivity of these to shallow abstraction.

- The confined aquifers below 20 m depth should be classified as Category C.

Groundwater allocation

- Aquifers in the Taratahi zone should be managed as a single groundwater system.

- Groundwater allocation should be referenced to specified depletion effects on the spring discharges along the Masterton and Carterton faults.

- The estimated MALF for total spring discharge in the zone is 100 L/s (8,640 m^3/day).

- The total groundwater allocation should not exceed 20-30% of the reference LSR (lower quartile).

- The surface water (spring) depletion factor in this zone should be 0.22.

Table E9 outlines potential groundwater allocation options for the Taratahi zone based on management of the cumulative effects on stream baseflow.

Option 1 is recommended in recognition of the fact that some of the springs emanating from this zone flow into the over-allocated Parkvale Stream and Booths Creek system.

Table E9: Groundwater allocation options for the Taratahi water management zone

Options	Cumulative depletion effect	Allocation* (m^3/day)	Allocation** (m^3/year x 10^6)	% LSR***
1	20% MALF	7,900	1.14	17
2	30% MALF	11,800	2.12	26
3	40% MALF	15,700	2.82	35

* Allocation = x % MALF / depletion factor

** Annual allocation is based on 180 days pumping per year.

*** LSR – lower quartile annual land surface recharge (for reference only)

E.8 Fernhill-Tiffen water management zone

E.8.1 Overview

Delineation: The Fernhill-Tiffen water management zone is a geologically and hydrologically distinct area of elevated older terrace deposits located between the Ruamahanga River and the Parkvale-Taratahi zones (Figure E37). Groundwater and surface water in the zone discharge towards the Ruamahanga River. The zone also incorporates the uplifted Tiffen Hill block.

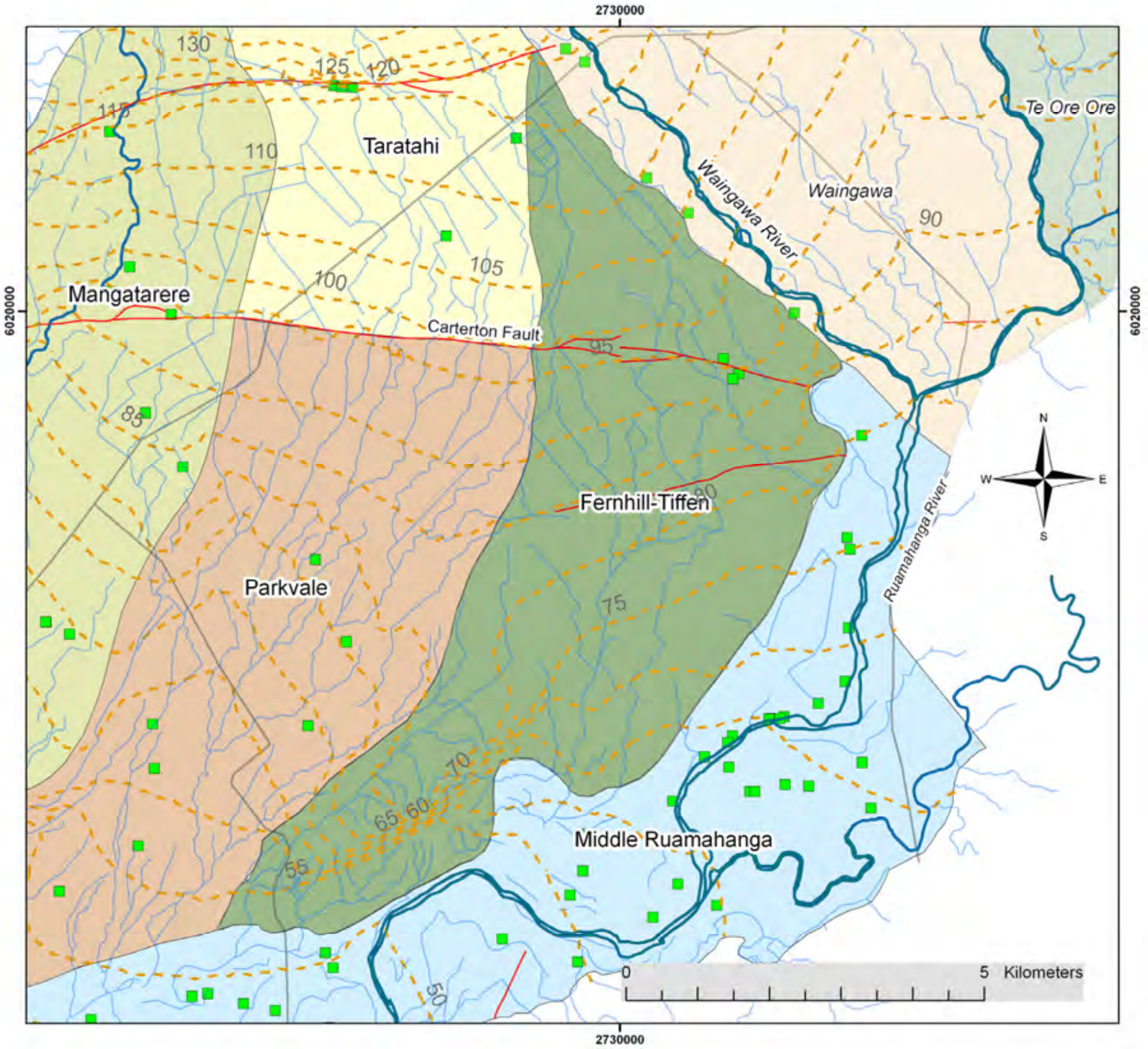

Figure E37: The Fernhill-Tiffen water management zone map showing existing groundwater bores with consented abstraction (green squares) and simulated groundwater flow contours (brown dashed lines at 5 m intervals in metres above mean sea level).

Area: 38.1 km^2.

Boundaries: The eastern boundary follows a prominent terrace edge between younger Q2 deposits on the Ruamahanga valley and an elevated Q4 and older sequence to the west. The western

	boundary follows a surface water divide between the Fernhill and Parkvale areas.
	The northern zone boundary is coincident with the terraced edge of the Q1 deposits of the Waingawa River.
Principal surface water systems:	None.
Aquifer sequences:	Heterogeneous sequence of generally low-permeability alluvium. Single leaky groundwater system with poor resource potential.
Recharge:	Average annual recharge is 3.25 x 10^6 m^3.
Existing RFP zones:	Fernhill, Parkvale (east). Existing groundwater allocation from each of these zones is shown in Table E10.

Table E10: 'Safe yield' estimates and groundwater allocation status for existing RFP groundwater zones (WRC 1999) located within the Fernhill-Tiffen water management zone

Existing RFP zone	RFP 'safe yield' (m^3/year)	Current allocation		% allocated
		(m^3/day)	(m^3/year)	
Fernhill	4.7 x 10^6	4,039	0.753 x 10^6	16

E.8.2 Current consented groundwater abstraction in the Fernhill-Tiffen zone

As at June 2010, there are currently three bores with consented abstraction in the Fernhill-Tiffen zone with a combined allocation of 2,400 m^3/day. The bore locations are shown on Figure E37.

E.8.3 Hydrogeology summary

The Fernhill-Tiffen area is a 'block' of uplifted older terrace deposits and basement greywacke (exposed on Tiffen Hill). The sediment sequence is dominated by dense, poorly sorted silty-sandy fan gravels of Q4 age and older which generally yield limited volumes of groundwater. In some areas, such as adjacent to the Carterton Fault, higher bore yields can be obtained.

The zone has a covering of several low-permeability loess sequences which strongly influence the rainfall recharge dynamics. Groundwater level trends show long wavelength sinusoidal water level fluctuations occur over several years, a pattern typical of aquifers which receive rainfall recharge pulses transmitted very slowly through a thick and low permeability unsaturated zone. The zone exhibits temporal groundwater level variations which closely reflect the long-term rainfall pattern.

E.8.4 Zone management objective

There are no surface water systems in this zone apart from a network of artificial water race channels and ephemeral runoff streams. The principal management objective for the Fernhill-Tiffen zone is to ensure the sustainable use of groundwater resources by having specific regard to:

- Rainfall recharge
- Interference effects on existing groundwater users

Interference effects on existing groundwater users will be addressed by specific policy rules. Therefore, the allocation volume for this zone should be based upon a proportion of calculated rainfall recharge.

E.8.5 Numerical modelling

Baseline water balance

The numerical groundwater flow model was used to quantify the natural water balance for the Fernhill-Tiffen zone by running the model for a period of 15 years (1992 to 2006). Figure E38 shows the modelled annual rainfall recharge for the period 1992 to 2007 derived from soil moisture balance modelling. The average annual recharge for the zone is 3.25 x 10^6 m^3 and the annual lower quartile recharge is 1.51 x 10^6 m^3.

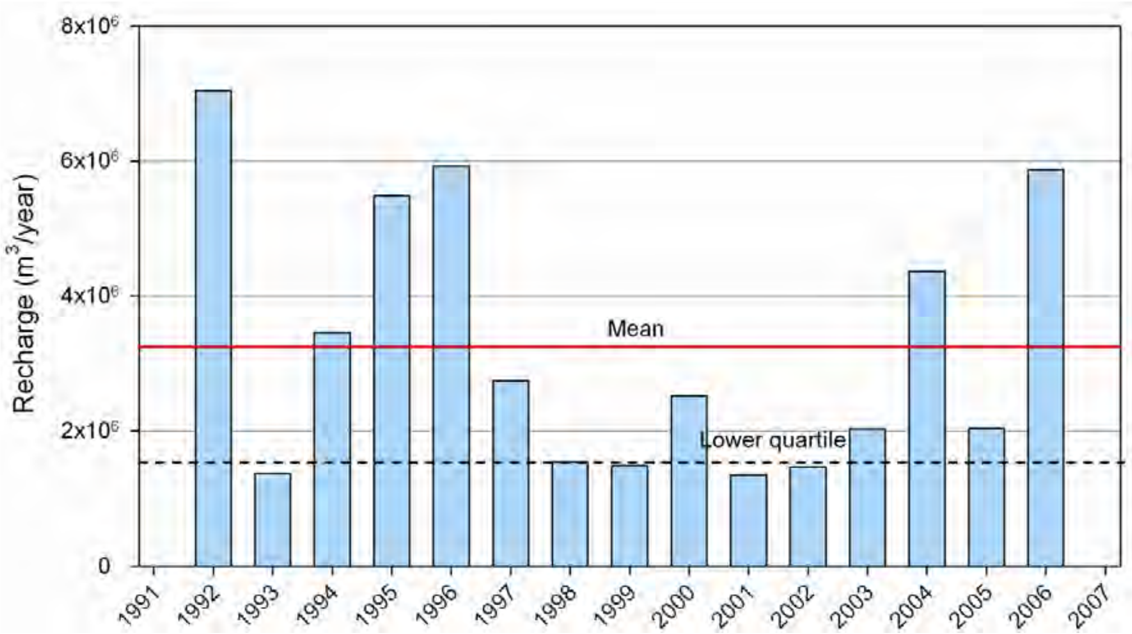

Figure E38: Modelled annual rainfall recharge (1992–2006) for the Fernhill-Tiffen water management (mean recharge is 3.25 x 10^6 m^3/year; lower quartile annual recharge is 1.51 x 10^6 m^3)

Relatively small quantities of groundwater is currently abstracted from the Fernhill-Tiffen zone and the three bores with consented abstraction are located along the Carterton Fault (Figure E37). Figure E39 shows the estimated consented abstraction which commenced in 2002. The peak estimated abstraction is about 1,200 m^3/day which is 50% of the consented abstraction rate of 2,400 m^3/day.

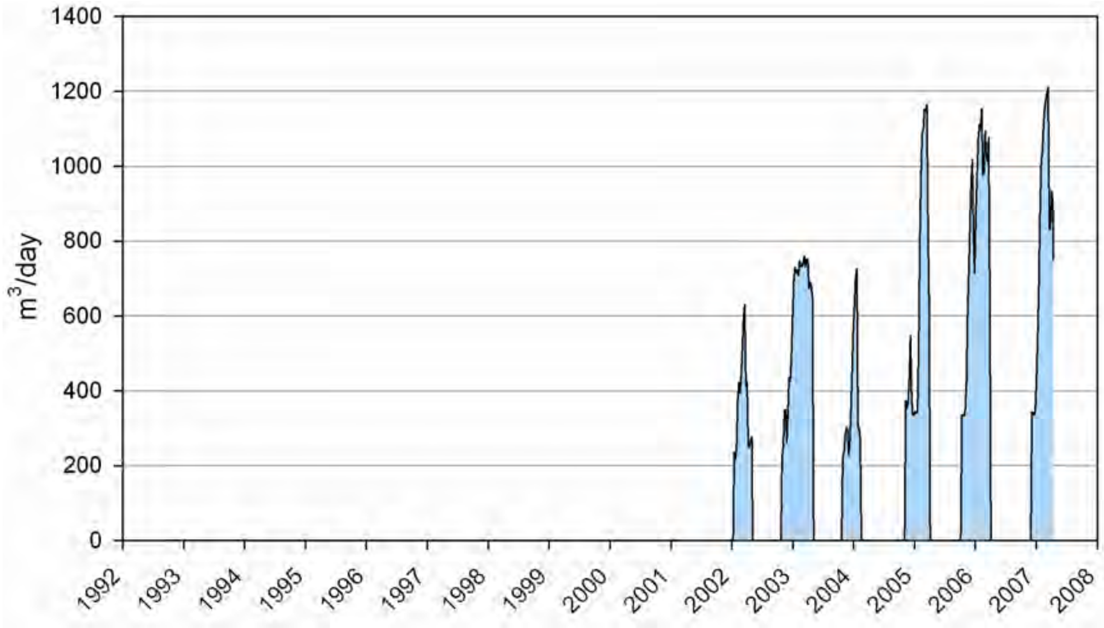

Figure E39: Simulated historical abstraction in the Fernhill-Tiffen zone. (Note there are only three consented takes in this zone and there was no consented abstraction prior to 2002).

E.8.6 Groundwater management options for the Fernhill-Tiffen water management zone

Groundwater-surface water interaction zones

- The entire Fernhill-Tiffen zone should have a Category C classification since there are no hydraulically connected surface water systems in the local area.

Groundwater allocation

- The heterogeneous mid-late Quaternary sequence in the Fernhill-Tiffen zone should be managed as a single aquifer.

- Since depletion of surface water is not of concern in this zone and because of the generally low resource potential of the low permeability aquifers, allocation management options should be based upon a proportion of land surface recharge (calculated as the annual lower quartile volume). As a general guide, allocation of 20 to 30% of the lower quartile LSR is recommended, but since there are no hydraulically connected waterways in this zone, allocation could reasonably exceed this.

Table E11 provides groundwater allocation options for the Fernhill-Tiffen zone. Option 3 is recommended for the reasons discussed above.

Table E11: Groundwater allocation options for the Fernhill-Tiffen zone

Options	Allocation reference	Allocation* (m^3/day)	Allocation (m^3/year x 10^6)
1	40% LSR	3,400	0.61
2	50% LSR	4,200	0.76
3	80% LSR	6,700	1.2

LSR = lower quartile annual land surface recharge (rainfall recharge).
* Daily allocation is calculated by dividing the annual allocation by 180 days.

E.9 Middle Ruamahanga water management zone

E.9.1 Overview

Delineation: The Middle Ruamahanga water management zone represents a 16 km reach of the Ruamahanga River between the Waingawa River confluence and the Waiohine River confluence (Figure E40). The zone consists largely of recent, highly permeable Q1 alluvium but also marginal older (Q2+) terraces.

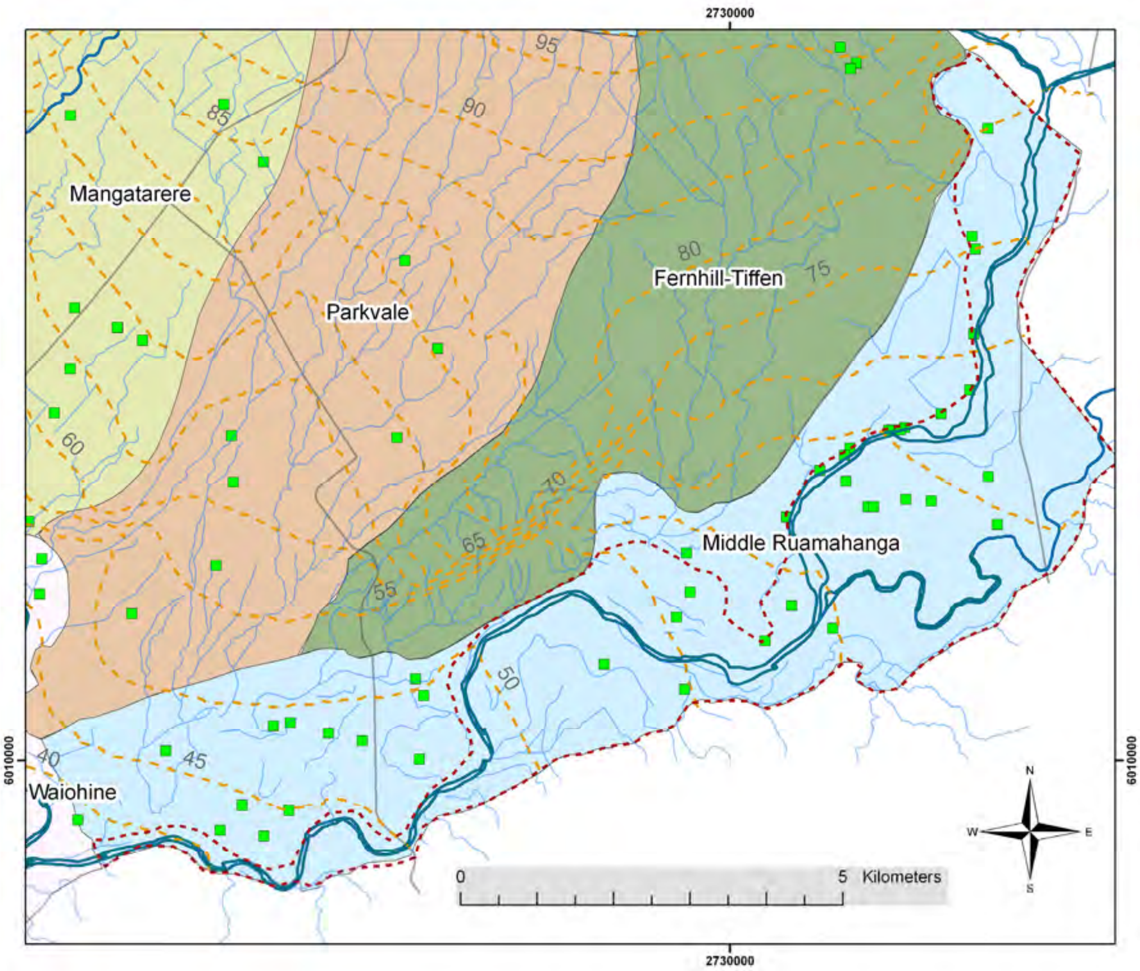

Figure E40: The Middle Ruamahanga water management zone map showing existing groundwater bores with consented abstraction (green squares), groundwater flow contours (brown dashed lines at 5 m intervals) and extent of Q1 alluvium (dashed red line)

Area: 43.8 km^2.

Boundaries: The western boundary is coincident with a prominent terrace which marks the edge of the Fernhill-Tiffen zone. The eastern boundary represents the edge of the Middle Valley groundwater system and follows the contact between late Quaternary alluvium and the early-mid Quaternary or Tertiary eastern hills sequences.

The southern zone boundary follows a flow line segregating the Parkvale zone from the Waiohine water management zone while the northern edge represents the upstream boundary of the Middle Valley catchment.

Principal surface water system: Ruamahanga River.

Aquifer sequences: Shallow unconfined aquifer to 10–15 m depth.

Recharge: Estimated average annual rainfall recharge is 5.12 x 10^6 m^3.

Existing RFP zones: Middle Ruamahanga (shallow and deep aquifers). Table E12 summarises the existing allocation status of these zones.

Table E12: 'Safe yield' estimates and groundwater allocation status for existing RFP groundwater zones (WRC 1999) located within the Middle Ruamahanga water management zone.

Existing RFP zone	RFP 'safe yield' (m^3/year)	Current allocation		% allocated
		(m^3/day)	(m^3/year)	
Middle Ruamahanga ('shallow aquifers')	7.3 x 10^6	39,900	7.3 x 10^6	100
Middle Ruamahanga ('deep aquifers')	2.2 x 10^6	7,900	1.56 x 10^6	76
Total	9.5 x 10^6	40,600	8.86 x 10^6	93

E.9.2 Current abstraction from the Middle Ruamahanga zone

As at June 2010, current consented groundwater abstraction from the Middle Ruamahanga zone totals 49,300 m^3/day from 43 bores (shown on Figure E40). Total consented abstraction from the Q1 gravels in this zone is 29,500 m^3/day (29 bores), with 19,800 m^3/day associated with Q2+ terraces at the southern end of the zone.

E.9.3 Hydrogeology summary

The Middle Ruamahanga zone is characteristised by a highly dynamic unconfined to semi-confined (Q1+Q2) aquifer system comprising permeable gravels some 10 to 20 m thick. The aquifer exhibits a high degree of connectivity with the Ruamahanga River. Substantial groundwater abstractions in the Middle Valley catchment occur from either very shallow bores, or from slightly deeper waterbearing layers (typically 15 to 20 m below ground). Overall, the aquifer system is generally less than 15 m deep in the northern part of the zone, deepening to 20 to 30 m in the southern part. An older terrace sequence (Q2+) intermittently occurs along the Tiffen-Fernhill boundary, the largest area being directly south of Tiffen Hill (near the Waiohine zone boundary) where localised subsidence appears to have created a small depositional basin in which a number of high-yielding bores are located.

E.9.4 Hydrology

The Ruamahanga River is the the principal drainage system of the Wairarapa Valley. Between the Waingawa River and the Waiohine River confluences, a length of approximately 20 km, the river alternates between semi-braided and single thread form and exhibits a complex interaction with groundwater. The relatively large rates of flow in this river (mean annual low flow = 2.7 m^3/s) mean that it only possible to detect general losing and gaining patterns given the standard gauging error of +/- 10%. Between the Waingawa confluence and Gladstone bridge the river neither significantly gains nor loses flow (it is ‘neutral’). Between Gladstone bridge and Kokotau bridge the river gains approximately 1 m^3/s (86,400 m^3/day) of flow (during summer) from groundwater seepage.

E.9.5 Zone management objective

The principal management objective for groundwater allocation in the Middle Ruamahanga zone is to ensure the sustainable use of groundwater resources while protecting the instream values of hydraulically connected surface water ecosystems.

Within the Middle Ruamahanga zone, only the Ruamahanga River has a direct connection to the groundwater environment and therefore the protection of baseflow in this river is of primary importance.

E.9.6 Numerical modelling

<u>Baseline water balance</u>

The numerical groundwater flow model was used to quantify the natural water balance for the Middle Ruamahanga zone by running the model for a period of 15 years (1992 to 2007) with no groundwater abstraction occurring. This scenario provides a baseline simulation against which the effects of abstraction can be evaluated. Of particular relevance to assessing the sustainability of abstraction, the model provides information on the cumulative depletion effects of groundwater pumping on the surface water environment.

The principal water balance components for the Middle Ruamahanga zone are rainfall recharge and groundwater discharge to the Ruamahanga River. Figure E41 shows the modelled annual rainfall recharge for the Middle Ruamahanga zone for the period 1992 to 2006. The average annual rainfall recharge for this period is 5.7×10^6 m^3.

Figure E42 shows the total simulated groundwater discharge to the Ruamahanga River in the Middle Ruamahanga zone. The model predicts a mean net groundwater discharge to the river of about 50,000 m^3/day (0.6 m^3/s), broadly consistent with measured flow gains within the zone.

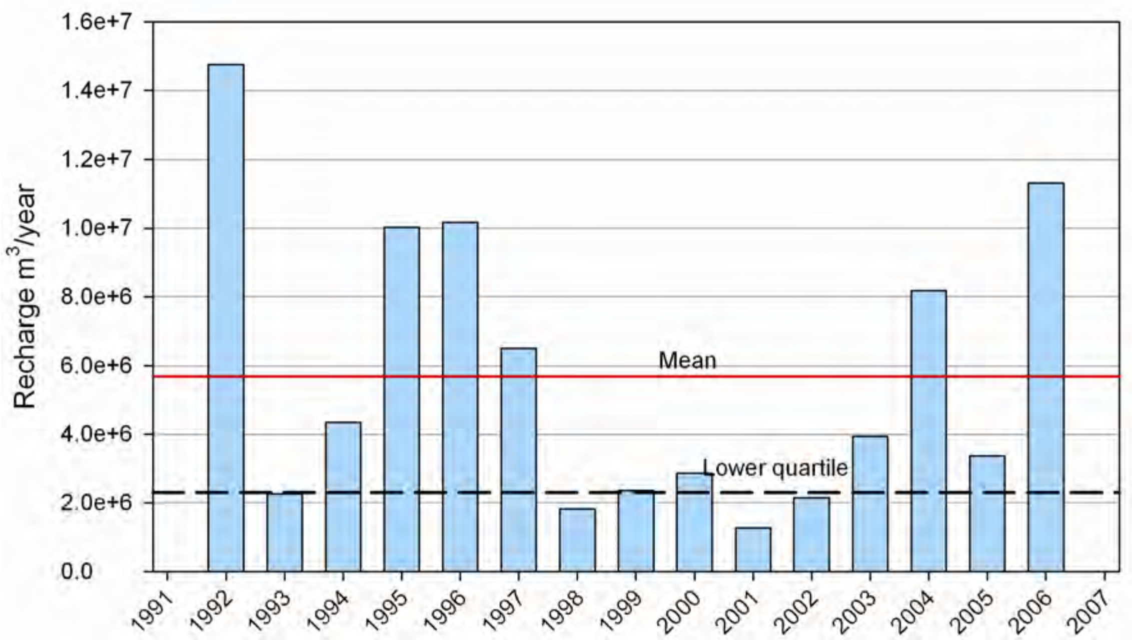

Figure E41: Modelled annual rainfall recharge for the Middle Ruamahanga water management zone for the period 1992–2006 (mean annual recharge is 5.7 x 10^6 m^3 and the annual lower quartile recharge is 2.3 x 10^6 m^3)

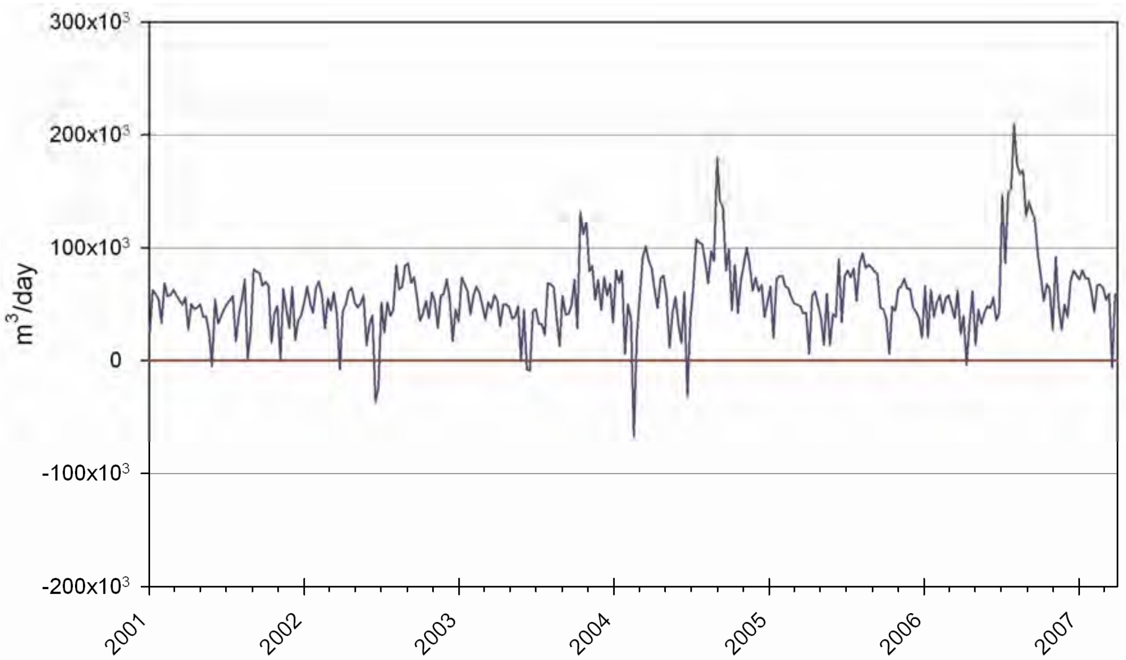

Figure E42: Simulated groundwater discharge to the Ruamahanga River in the Middle Ruamahanga zone when there is no groundwater abstraction (2001 to 2007). A positive flux shows a net discharge from groundwater to the river. The plot indicates a consistent flow gain due to groundwater discharge averaging about 50,000 m^3/day (0.6 m^3/s).

Modelled abstraction effects 1992–2007

Groundwater abstraction from the Middle Ruamahanga zone was simulated for the 15-year transient model run and is shown in Figure E43. Seasonal abstraction has increased significantly since about 1998 and peaked at approximately 17,000 m^3/day during the

2006/07 irrigation season (estimated actual abstraction). Also shown is the abstraction from the shallow Q1 gravels only (which totals approximately 8,000 m^3/day).

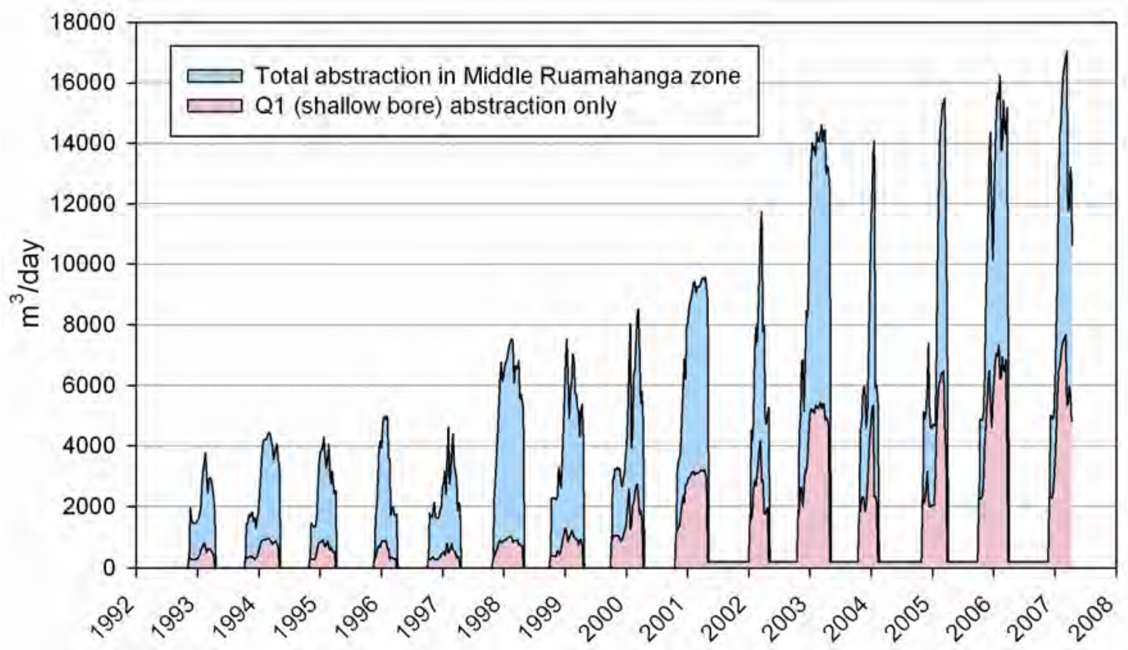

Figure E43: Simulated historic abstraction in the Middle Ruamahanga zone between 1992 and 2007 showing total abstraction and abstraction from Q1 gravels only

The numerical groundwater flow model was used to calculate the depletion effects associated with the estimated abstraction (shown in Figure E43) on the Ruamahanga River. Figure E44A shows the simulated surface water depletion resulting from historical abstraction. The model predicts that total seasonal depletion is between 75 and 85% of the total abstraction rate thereby indicating a high degree of connectivity between the aquifer and the river in this zone. Figure E44A also shows the proportion of the total take derived from very shallow Q1 bores and the associated river depletion rate which approaches 100% of the abstraction rate (q/Q = 1).

Figure E44B shows in detail the simulated depletion curve over the 2000–01 irrigation season for both total pumping and Q1 pumping only. The lag times for the two sets of pumping bores are distinctive, with the Q1 bores causing a faster depletion and showing a more immediate reduction in depletion when pumping stops. However, in both instances, the model shows that all groundwater abstraction within the Middle Ruamahanga zone results in a substantial direct depletion of the river.

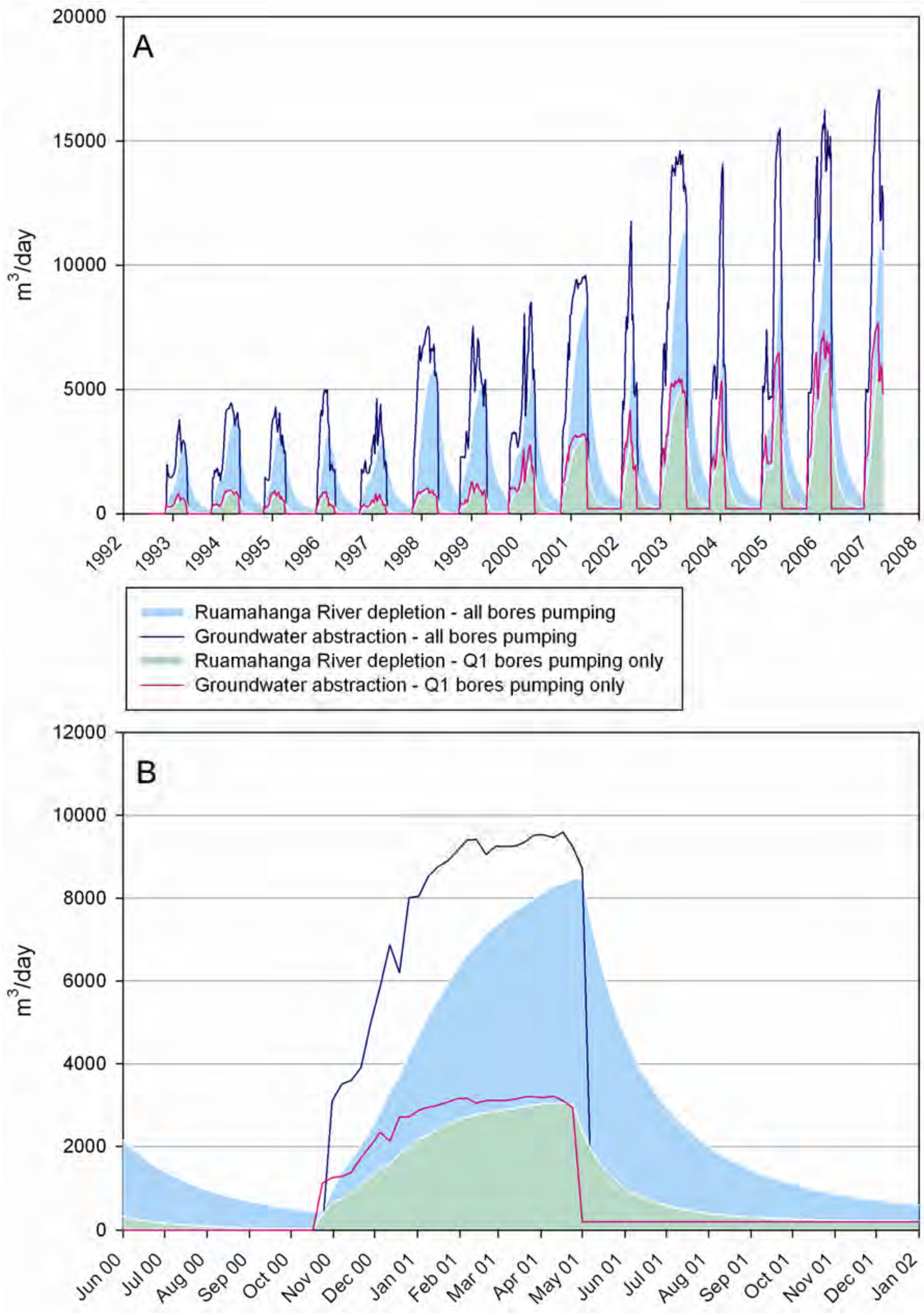

Figure E44: Simulated surface water depletion resulting from historic abstraction in the Middle Ruamahanga zone from all bores, and from Q1 bores only. A: full model run and B: June 2000 to January 2002.

E.9.7 Groundwater management options for the Middle Ruamahanga water management zone

Groundwater-surface water interaction zones

- Due to the high degree of connectivity between the aquifers (unconfined and semi-confined) and the Ruamahanga River, the entire Middle Ruamahanga zone should be classified as Category A.

Cross-zone depletion effects

- The reduction in throughflow to the Middle Ruamahanga zone resulting from abstraction in the adjoining Parkvale zone should be accounted for in the allocation scheme for this zone using the following relationship:

*Cross-zone depletion effect = Parkvale (confined) zone allocation * 0.12*

Groundwater allocation

- Groundwater allocation is not required for this zone since all groundwater takes will be managed as part of the allocation for the Ruamahanga River under the Category A classification.

Appendix F

Appendix F: Lower Valley groundwater allocation framework

This Appendix sets out a framework for the sustainable allocation of groundwater in the Lower Valley catchment of the Wairarapa Valley. It contains a summary of the hydrogeological setting of the Lowerr Valley as a whole and then discusses potential allocation regimes for each of the management zones within the Lower Valley.

F.1 Summary of Lower Valley catchment hydrogeology

The hydrogeology of the Lower Valley catchment is described in detail by Gyopari and McAlister (2010c). A summary of the key features of the Lower Valley catchment is provided in the following section.

The Lower Valley groundwater catchment has an area of 643 km^2 and encompasses Lake Wairarapa, Lake Onoke, the Martinborough Terraces and the Tauherenikau fan. The catchment contains the lower reaches of the Ruamahanga River and its main eastern tributary, the Huangarua River. Smaller tributaries draining the Aorangi Range near the coast include the Dry, Tauanui and Turanganui rivers. The Tauherenikau River is another major drainage system which is sourced in the Tararua Range and flows into Lake Wairarapa.

The tectonically complex Lower Valley groundwater 'basin' contains a heterogeneous unconsolidated sequence of late Quaternary fluvial, lacustrine and estuarine sediments. Major fault and fold structures have influenced the drainage patterns and depositional environments of the sedimentary sequence. Fault blocks of older, less permeable sediments and basement greywacke rock have been uplifted and displaced against younger water-bearing strata around Te Maire ridge, the Martinborough Terraces and in the Onoke area. Structural deformation is also responsible for the creation of a large subsiding basin centred on Lake Wairarapa in which multiple sequences of thin re-worked gravel aquifers are separated by thick, fine-grained lacustrine and estuarine deposits.

On a broad scale, the hydrogeological setting comprises a shallow unconfined flow system which is connected to rivers and streams where permeable Holocene alluvium occurs (particularly along the Ruamahanga and Tauherenikau rivers). On the eastern side of the valley, the Ruamahanga River has carved a shallow channel between Te Maire ridge and the eastern hills where groundwater and surface water are very closely interconnected. Relatively low permeability, poorly-sorted fan gravels occur on the western side of the valley against the Tararua Range which distally grade and segregate into a sequence of discrete re-worked permeable confined aquifers in the Lake basin area. Intervening poorly sorted gravels and fine grained interglacial aquitards confine and separate reworked gravel intervals.

Conceptually, the Lower Valley groundwater catchment is a 'closed' groundwater system in which the dominant water balance components are rainfall recharge, fluxes between surface water and groundwater and abstraction. Geological constraints at the coast permit very a limited connection between the groundwater system and the sea. Rainfall recharge exhibits a very pronounce spatial pattern due to the very steep rainfall gradient across the valley (1,900 mm in the west to 800 mm in the east). The average annual recharge over a 16-year period between 1992 and 2008 was 47.3 x 10^6 m^3/year (Gyopari and McAlister 2010c).

F.2 Water management zones

Managing the cumulative effects of groundwater abstractions with a moderate to low hydraulic connection to surface water has been approached by delineating '*water management zones*' within each of the three Wairarapa Valley catchments (Upper, Middle and Lower). These zones are essentially management units based on groundwater and surface water sub-catchment mapping which may also (or alternatively) represent distinct hydrogeological domains. Zone delineation criteria include surface water catchment boundaries, hydraulic or physical groundwater flow system boundaries, the conceptual hydrogeological functioning of the zone and its context within the larger groundwater catchment.

The zones are designed so that the management of surface water resources can be easily integrated with groundwater allocation, thereby allowing the cumulative effects of groundwater abstraction on sub-catchment baseflow to be accounted for at a catchment scale (i.e. enabling conjunctive management of groundwater and surface water resources).

It is important to recognise the water management zones are not, in most instances, isolated management units. Most zones have 'soft' boundaries based on hydraulic divides or represent transitional areas within a continuous groundwater flow system. Where significant interactions between zones are recognised, the sensitivity of cross-zone groundwater fluxes to the cumulative effects of abstraction has been evaluated and provision made in the allocation options.

Figure F1 shows the spatial distribution of the eight 'water management zones' for the Lower Valley catchment which are summarised in Table F1. Unlike the Middle Valley catchment, the groundwater environment is considerably more complex and ranges from shallow, unconfined areas in close contact with the surface water environment, to deep confined aquifers (such as the Lake basin) which are remotely recharged from unconfined aquifer areas. The delineation of water management zones is therefore based upon the conceptual hydrogeological model and the recognition of distinct hydrogeological environments. The zone design takes into consideration surface water catchments in combination with groundwater recharge and discharge areas. The rationale behind the identification of each zone is provided in the relevant report sections and further detailed information is provided by Gyopari and McAlister (2010c).

Many of the Lower Valley water management zones are interconnected and represent parts of a continuous flow system from recharge areas on the Tauherenikau fan and Ruamahanga valley, to spring discharge areas on the lower fan areas and vertical leakage out of the Lake basin area. Water management zones which exhibit significant interdependence (or cross-zone interference effects), especially when they are pumped, are the Tauherenikau, Moiki, Lower Ruamahanga and Lake zones. The interactions between these zones and abstraction-induced interference effects between them were taken into consideration when developing recommendations for sustainable allocation options.

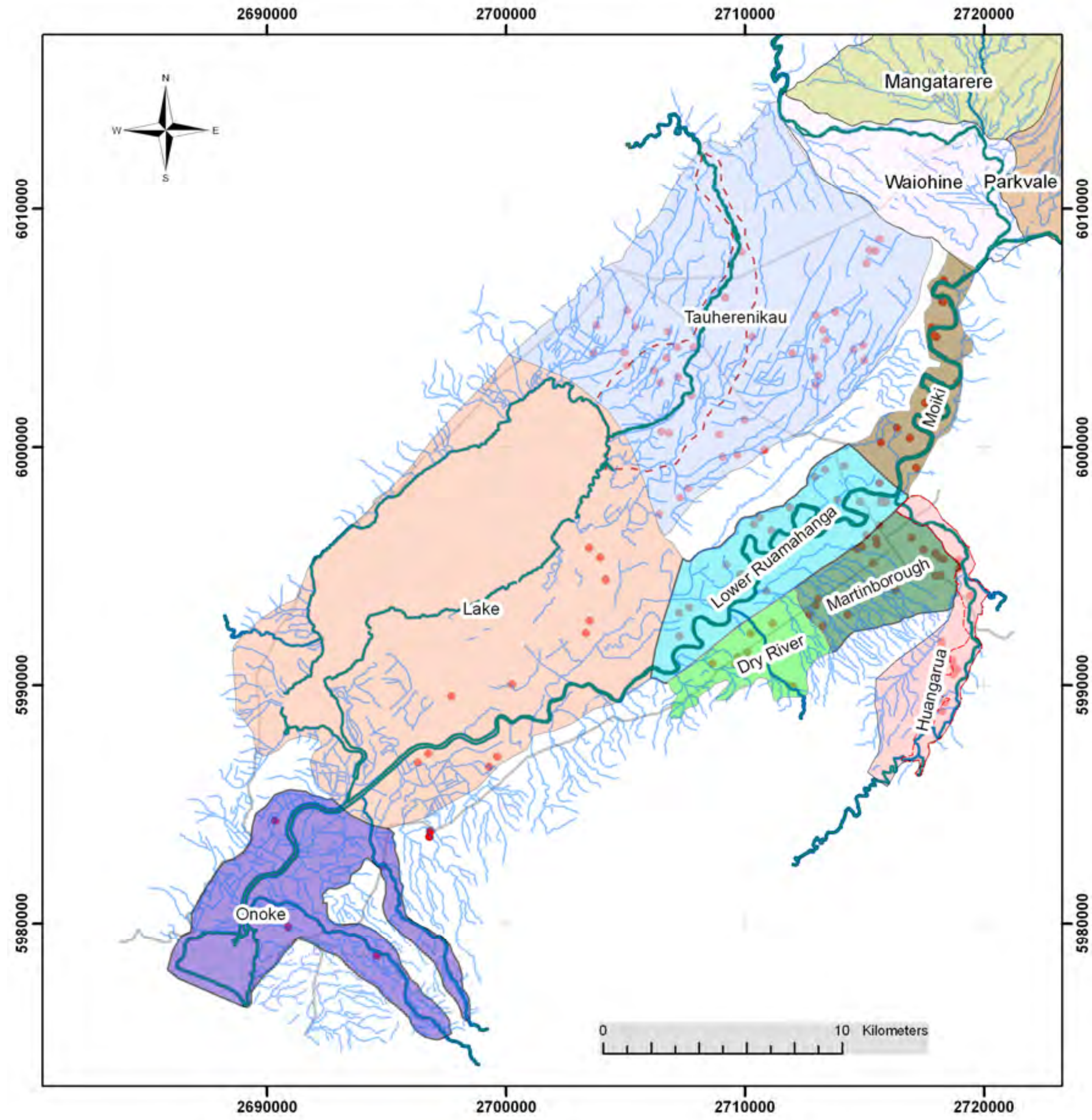

Figure F1: Management zones for the Lower Valley catchment. Consented groundwater abstractions are shown by red circles.

Table F1: Water management zones and management criteria for the Lower Valley catchment

Zone name	Area (km^2)	Aquifer type	Allocation criteria
Tauherenikau	152	Unconfined, semi-confined	Tauherenikau River Stonestead Creek Featherston springs Otukura Stream
Moiki	18	Unconfined	Ruamahanga River
Lower Ruamahanga	39	Unconfined, semi-confined	Ruamahanga River
Martinborough	22.4	Confined, semi-confined	Rainfall recharge
Dry River	16.7	Semi-confined	Rainfall recharge
Huangarua	22.5	Unconfined, semi-confined	Huangarua River Rainfall recharge
Lake	219.3	Confined	Lake Wairarapa Tauherenikau zone springs Ruamahanga River Drawdown
Onoke	40.4	Unconfined Confined	Turanganui River Tauanui River Throughflow recharge from side valleys Discharge to Ruamahanga River and Lake Onoke

Figure F2 shows the existing Regional Freshwater Plan (RFP) (WRC 1999) groundwater management zones in the Lower Valley catchment. The outlines of the new water management zones are superimposed on this map for cross-reference purposes.

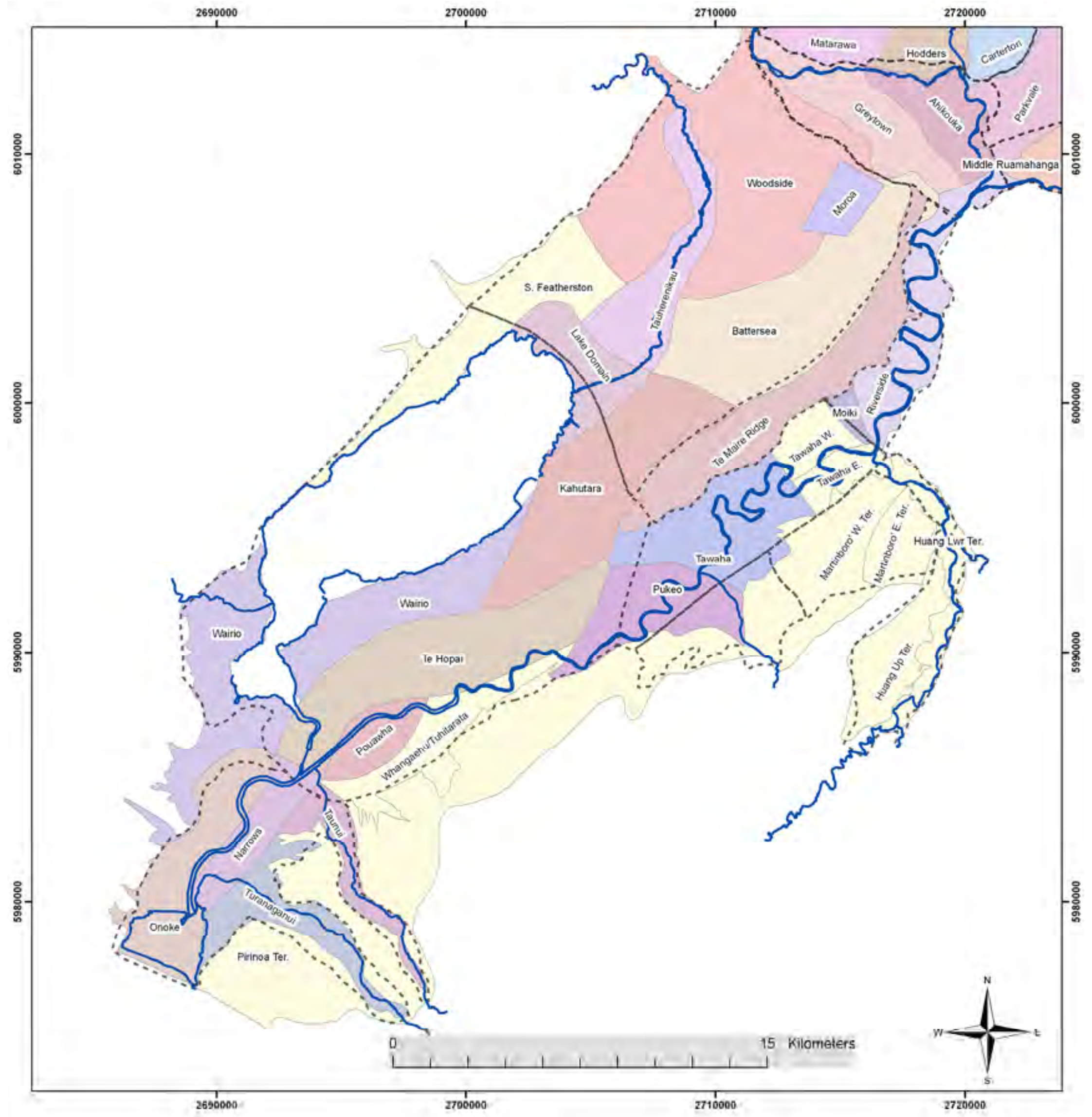

Figure F2: Map showing existing RFP (WRC 1999) groundwater management zones in the Lower Valley catchment with the outlines of the new water management zones also shown as dashed lines

F.3 Lower Valley catchment numerical groundwater model

The numerical groundwater flow model for the Lower Valley catchment was used to assess groundwater management options for each water management zone, considering surface water depletion effects, aquifer drawdowns, rainfall recharge and cross-zone throughflows associated with groundwater abstractions. Details of the model and its calibration are provided in Gyopari and McAlister (2010c).

Initially, the numerical groundwater flow model was used to quantify the natural water balances by running the model for the 16-year calibration period (1992 to 2008) with no abstraction. This scenario provided a 'baseline simulation' against which the effects of abstraction were evaluated, including assessment of the cumulative depletion effects of groundwater pumping on the surface water environment and cross-zone throughflow. For some sub-catchments, additional short scenarios were simulated to isolate abstraction effects associated with specific zones and to characterise potential intra-zone effects of abstraction.

F.4 Lake water management zone

F.4.1 Overview

Zone Delineation: The Lake zone is essentially defined by the deep depositional 'Lake basin' which hosts a series of confined aquifers. The zone contains Lake Wairarapa and the peripheral low-lying lake margin areas to the south and also the lower reaches of the Ruamahanga River (Figure F3).

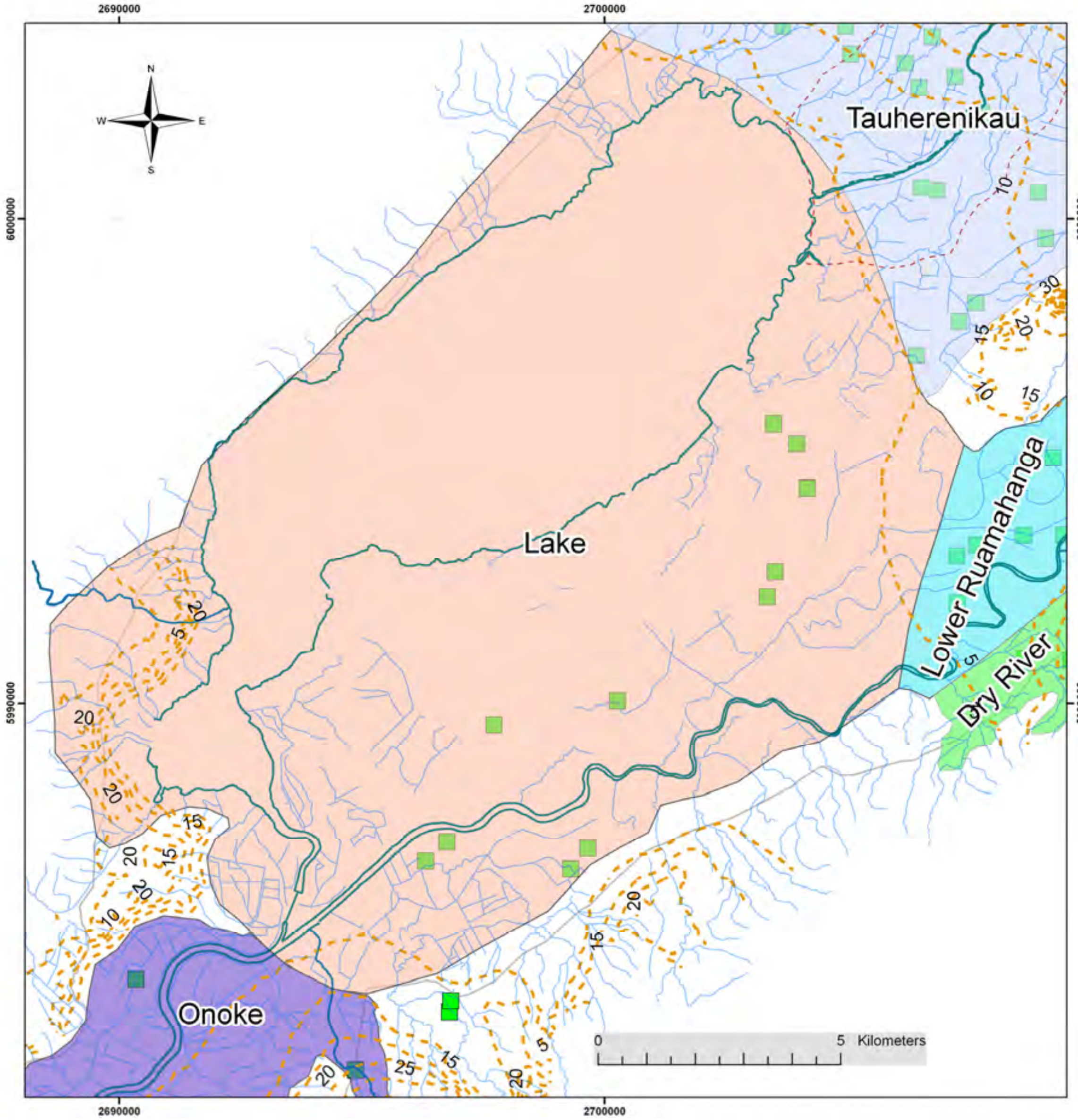

Figure F3: The Lake water management zone showing existing groundwater bores with consented abstraction (green squares), and simulated groundwater flow contours (brown dashed lines at 5 m; contour line following north-easterly lake margin is 5 m amsl). Note there is a very flat hydraulic gradient in this zone and most groundwater throughflow discharges into Lake Wairarapa.

Area:	219.3 km^2.
Boundaries:	The north-eastern, up-gradient boundary is coincident with a transition zone between the Tauherenikau fan unconfined and semi-confined aquifers (in the Tauherenikau zone) and the deep Lake basin confined aquifers. It is aligned with the northern margin of Lake Wairarapa and extends to the end of Te Maire ridge. There is groundwater throughflow across this boundary from the up-gradient Tauherenikau zone. The boundary with the Lower Ruamahanga water management zone also represents the transition from unconfined to semi-confined valley-fill alluvium into the discrete confined aquifers in the Lake basin. Model simulations indicate limited groundwater throughflow from the Ruamahanga valley into the deep Lake basin aquifers occurs across this boundary. The southern boundary with the Onoke zone marks the southern extent of the Lake depositional basin and reflects the rapid shallowing of the aquifer sequence. Deep confined aquifers do not appear to extend past this boundary. The boundary also approximately coincides with a groundwater divide and (somewhat counter-intuitively) there is a small volume of throughflow from the Onoke zone northwards into the Lake zone across this boundary. The south-eastern boundary represents the contact between late Quaternary alluvium and the raised low-permeability early-mid Quaternary or Tertiary eastern hills sequences. The north-western boundary is defined by the Wairarapa Fault and the occurrence of greywacke basement rock.
Principal surface water systems:	Lake Wairarapa, Ruamahanga River.
Aquifer sequences:	Intermittent shallow unconfined or semi-confined aquifers to 10 to 15 m depth. A least three confined aquifers (Q2, Q4, Q6). The most extensive is the Q2 aquifer which appears to continue into the Onoke zone.
Existing RFP zones:	Lower Valley and constituent sub-zones (Kahutara, South Featherston, Wairio, Pouawha).
Current groundwater abstraction:	As at June 2010, the current consented abstraction in the Lake zone is 36,000 m^3/day from 12 bores.

F.4.2 Hydrogeology summary

The Lake zone corresponds to the Lake Wairarapa depression ('lake basin') – a deep, actively subsiding basin centred on the lake and the area to the southeast. The basin is filled with fine-grained lacustrine and estuarine sediments to several hundred metres depth. Discrete gravel-rich deposits associated with fluvial deposition by the Tauherenikau and Ruamahanga rivers during cold climatic phases protrude into the subsiding basin.

Lake Wairarapa has historically been the focus for the main drainage systems in the Wairarapa Valley. The Ruamahanga River (before it was artificially diverted) used to loop back up-valley and discharge into the lake after clearing Te Maire ridge. The southern margin of the Lake zone is defined by uplift in the Onoke/coastal area, and the northern boundary coincides with the edge of the Tauherenikau fan. A thick (20 to 40 m) confining layer of post-glacial estuarine muds occurs near to the surface across the zone. This is overlain in places by surficial dune sands bordering the lake. A prominent gravel aquifer at the base of the muds, sourced from the Tauherenikau and Ruamahanga rivers, is thought to be 'Waiohine Gravel' (of Q2 last-glacial age). This is the principal aquifer in this area which extends through into the Onoke zone toward the south coast. At least two of deeper gravel aquifers (Q4 and Q6) have been identified within the predominantly silt and clay rich basin fill, although these do not seem to extend further south than the central part of the basin.

The confined aquifers in the Lake zone are recharged by throughflow derived from rainfall infiltration and river bed losses on the Tauherenikau fan to the north (Tauherenikau zone), and also from river bed losses in the Lower Ruamahanga zone. From these recharge areas, groundwater flows through discrete gravel aquifers which progressively develop and segregate into the lake basin where they become separated by thick aquitard sequences. The lake basin is therefore a largely closed system as model simulations indicate there is no throughflow into the Onoke zone and the coast (in fact piezometric contours suggest limited throughflow from the Onoke zone into the Lake zone via the Q2 gravels). The Lake zone is also a general groundwater discharge area via vertical and lateral leakage into Lake Wairarapa and its surrounding wetlands. Modelling studies indicate that the lake receives groundwater discharge in the order of 37,000 to 50,000 m^3/day from deep and shallow groundwater, approximately half of which appears to be sourced from the shallow aquifers bounding the lake in the Tauherenikau delta area.

F.4.3 Hydrology

The Ruamahanga River is the principal drainage system in the Lake zone. The river used to naturally discharge directly to Lake Wairarapa but was diverted in the 1960s via the 'Ruamahanga Diversion', part of a flood control scheme designed to enable the river to by-pass Lake Wairarapa and flow directly into Lake Onoke at the coast. The mean flow in the Ruamahanga River measured at Waihenga bridge (just downstream of the Huangarua River confluence) is 85.3 m^3/s and the naturalised 1-day mean annual low flow for the river within the Lake zone is estimated to be 11.8 m^3/s[30].

Through much of the Lake zone, the Ruamahanga River does not exhibit any significant groundwater interaction because it is separated from the confined aquifer sequence by a

[30] Cawthron Institute (2008). Instream flow assessment for the Lower Ruamahanga River. Report prepared for GWRC. 1-day MALF for reach between Bentleys Beach and Tuhitarata bridge.

thick estuarine/lacustrine low permeability aquitard. However, upstream in the Lower Ruamahanga zone, bed losses from the river provide recharge via groundwater throughflow into the Lake zone confined aquifers. Therefore, drawdowns in the Lake zone aquifers have the potential to propagate into the Lower Ruamahanga zone and induce further recharge from the Ruamahanga River.

Lake Wairarapa is about 18 km long by 6 km wide, with a total area of approximately 78 km^2. The lake is shallow (mostly less than 2.5 m deep) and receives the majority of its inflow from the Tauherenikau River and several small streams along the western shores (e.g. the Otukura Stream). Total surface water inflow during a stable summer low flow has been estimated to be about 2 m^3/s by GWRC[31]. The Ruamahanga River now only flows into the lake under flood conditions (having been diverted from the lake by the flood control scheme). Groundwater inflow is largely unknown. There is anecdotal evidence that the lake receives inflows via discrete springs on the lake bed and it seems probable that groundwater also discharges to the lake through the Tauherenikau River delta gravels. The hydrochemical characteristics of the lake provide evidence that it receives discharge from deep confined aquifers. Ongoing water conductivity profiling investigations by GWRC also provide evidence of lake bed spring discharge. In the absence of more robust data, groundwater input was estimated from numerical modelling by Gyopari and McAlister (2010c) to be about 400 L/s.

The exit from Lake Wairarapa to Lake Onoke is regulated by six barrage gates operated by GWRC under a resource consent provided for by the National Water Conservation Order for Lake Wairarapa. The lake level is artificially regulated by the barrage gates. Some natural fluctuations in lake level are caused by rainfall and the effect of wind. The mean lake level is 0.64 m amsl (recorded at Burlings).

F.4.4 Zone management objectives

The principal objectives of groundwater allocation in the Lake zone are to ensure the sustainable allocation of groundwater resources by having specific regard to:

- Protecting the instream values of surface water systems by preventing excessive baseflow depletion, and
- the avoidance of excessive seasonal drawdown in the confined aquifers.

The confined Lake zone aquifers are not directly connected to the surface water environment within the zone, but drawdowns within the confined aquifers propagate to recharge areas and have the potential to contribute to the cumulative depletion of surface water systems in adjacent water management zones. Surface water systems which may experience depletion effects resulting from groundwater abstraction in the Lake zone include:

- Ruamahanga River (Lower Ruamahanga zone)
- Tauherenikau River (Tauherenikau zone)
- Featherston springs (Tauherenikau zone)

[31] GWRC (2010, unpublished). *Improving our understanding of Lake Wairarapa hydrology*. Unpublished internal memo by M Thompson. Internal reference WGN_DOCS#842486.

- Stonestead Creek springs (Tauherenikau zone)
- Lake Wairarapa (Lake and Tauherenikau zones)

In terms of effects on Lake Wairarapa, abstraction within the Lake zone confined aquifers may influence shallow groundwater levels in the semi-confined transition area between the confined and unconfined parts of the system. This may in turn reduce vertical leakage and shallow groundwater throughflow to Lake Wairarapa.

F.4.5 Numerical modelling

The numeric groundwater flow model for the Lower Valley catchment was used to assess the sustainability of current groundwater abstractions and to develop allocation options for the Lake water management zone. Details of the model and its calibration are provided by Gyopari and McAlister (2010c). It should be noted that the transient flow model uses a seven-day stress period, therefore all fluxes provided in the model outputs represent seven-day averages.

<u>Zone water balance</u>

The numerical model was initially employed to quantify the ‘natural’ water balance for the Lake zone over the 16-year calibration simulation (1992 to 2008) with no groundwater abstraction occurring. This scenario provides a baseline simulation against which the effects of abstraction can be evaluated using subsequent pumping simulations. Of particular relevance to assessing the sustainability of abstraction, the model provides information on the cumulative depletion effects of groundwater pumping on the surface water environment within the Lake zone and in adjacent zones.

The principal water balance components for the Lake zone are groundwater throughflow from the Tauherenikau fan and Ruamahanga valley, and groundwater discharge to Lake Wairarapa. There is also a relatively minor interaction between the Ruamahanga River and the groundwater system. Direct rainfall recharge is not a significant component of the water balance of the confined aquifers in this zone. However, on a local scale, recharge to surficial dune sands may be important (this aquifer is not simulated in the Lower Valley numerical model).

Figures F4 and F5 respectively show the simulated natural (i.e. no groundwater abstraction) groundwater discharge into Lake Wairarapa and groundwater throughflow into the Lake zone.

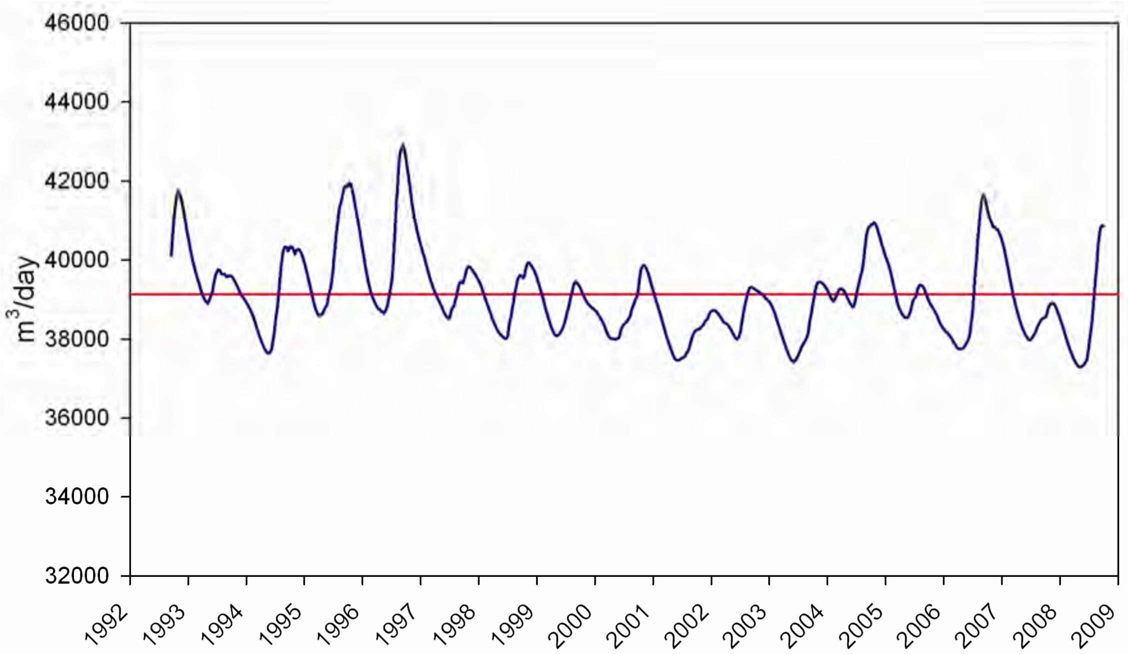

Figure F4: Modelled groundwater discharge to Lake Wairarapa in the absence of groundwater abstraction in the Lower Valley catchment between 1991 and 2008. The mean annual discharge to the lake is approximately 39,000 m^3/day (red line) and about 37,000 m^3/day during summer.

Figure F4 shows that the mean groundwater discharge to the lake is about 37,000 m^3/day and fluctuates seasonally by 2,000 to 4,000 m^3/day (highest in winter, lowest in summer). Figure F5 shows that the lake discharge can be accounted for by natural throughflow recharge, mostly from the Tauherenikau fan with a small input from the Ruamahanga valley. The simulated baseline recharge from the Tauherenikau fan is about 37,500 m^3/day with up to about 5,000 m^3/day from the Ruamahanga valley (Note: throughflow was calculated using the areas of vertical planes between Te Maire ridge and the Wairarapa Fault, and between Te Maire ridge and the southern edge of the Quaternary aquifer succession at the Eastern Hills contact. Throughflow calculations were undertaken using the FEFLOW groundwater model). It is also noted that natural throughflow quantities are particularly sensitive to groundwater abstraction in the Lake zone as described in Section F.4.5.

Abstraction from the Lake zone was simulated for the 16-year transient model run and is shown in Figure F6. Seasonal abstraction has increased significantly since about 2,000 and now peaks at approximately 25,000 m^3/day. The 2007/08 season abstraction is based upon actual meter data whereas earlier years have been estimated. The current consented abstraction in the zone is about 36,000 m^3/day and therefore actual (peak daily) use is about 70% of the consented rate.

The flow balances described above clearly indicate that when the confined aquifers in the Lake zone are pumped, a significant proportion of the water is derived from aquifer storage (since aquifer throughflow cannot sustain the combined pumping rates and discharge fluxes to the lake).

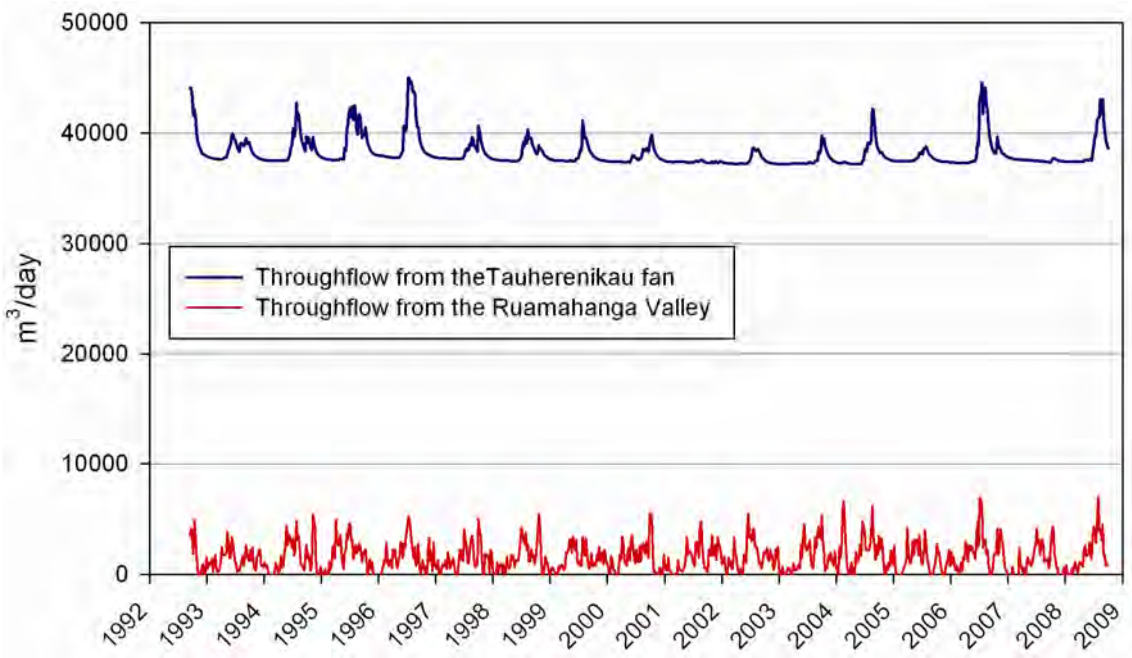

Figure F5: Simulated (natural) groundwater throughflow into the Lake zone from the Tauherenikau fan and Ruamahanga valley for the period 1992 to 2008 with no abstraction simulated. The plot shows the considerably greater contribution from the Tauherenikau fan recharge areas.

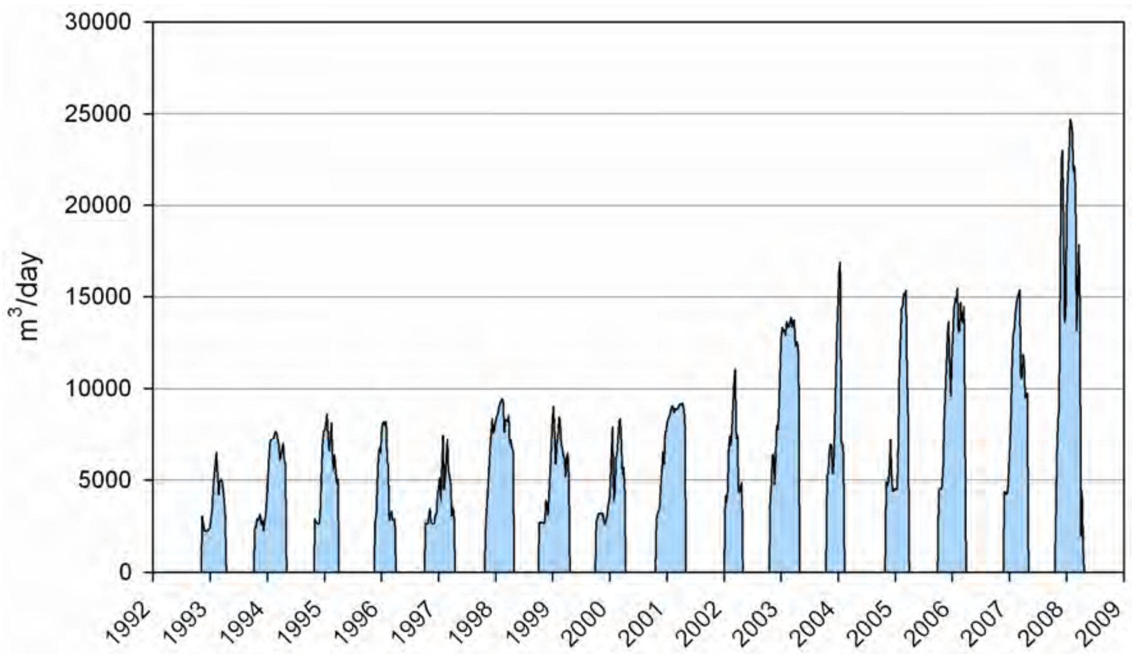

Figure F6: Simulated abstraction in the Lake zone from 12 bores with consented takes peaking at about 25,000 m^3/day during the 2007/08 irrigation season (most bores were metered weekly during the 2007/08 irrigation season)

Even though aquifer throughflows are enhanced during pumping, Figure F7 illustrates the change in the groundwater storage dynamics during pumping and non-pumping cycles. The model output shows that about 70% of the seasonal pumping rate is derived from storage which results in a corresponding decline in aquifer levels.

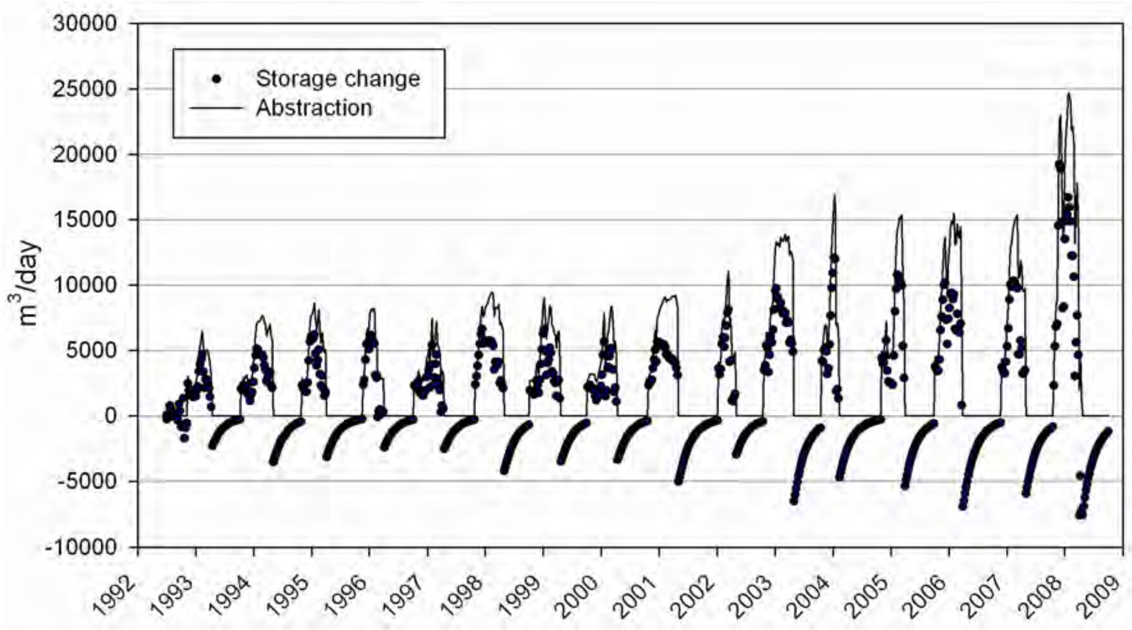

Figure F7: Simulated storage utilisation in the Lake zone confined aquifer system. A positive change shows water being drawn out of storage (groundwater levels respond by dropping). Negative values show storage replenishment when pumping ceases (i.e. seasonal storage replenishment is initially high and then slowly recedes as aquifer levels recover).

Drawdown assessment

The numerical groundwater model was used to characterise the spatial extent and magnitude of drawdown associated with abstraction within the Lake zone only. Using a version of the model in which all abstractions in the Lower Valley catchment other than those in the Lake zone were turned off, the modelled drawdown pattern associated with peak abstraction of the 2007/08 irrigation season is shown in Figures F8 and F9.

Figure F8 shows that seasonal abstraction from the Q2 and Q4 confined aquifers result in a 3 to 4 m drawdown in the central part of the Lake basin. The drawdowns extend both north and south of the Lake zone boundaries into neighbouring zones. In the north, small drawdowns of 0.1 m or less occur around the Tauherenikau delta and beneath the Featherston/Stonestead Creek area. From Figure F9, the northerly limit of drawdown appears to be about observation point 68/69 in the Stonestead Creek area, about 3 km north of the Lake zone boundary. Similarly, the drawdown effects also extend up the Ruamahanga valley into the Lower Ruamahanga zone to around observation point 79 (shown on Figure F9) in the Dry River area. The propagation of drawdown effects into neighbouring zones suggests that abstraction from the Lake zone confined aquifers has the potential to induce surface water depletion effects in the upstream recharge areas.

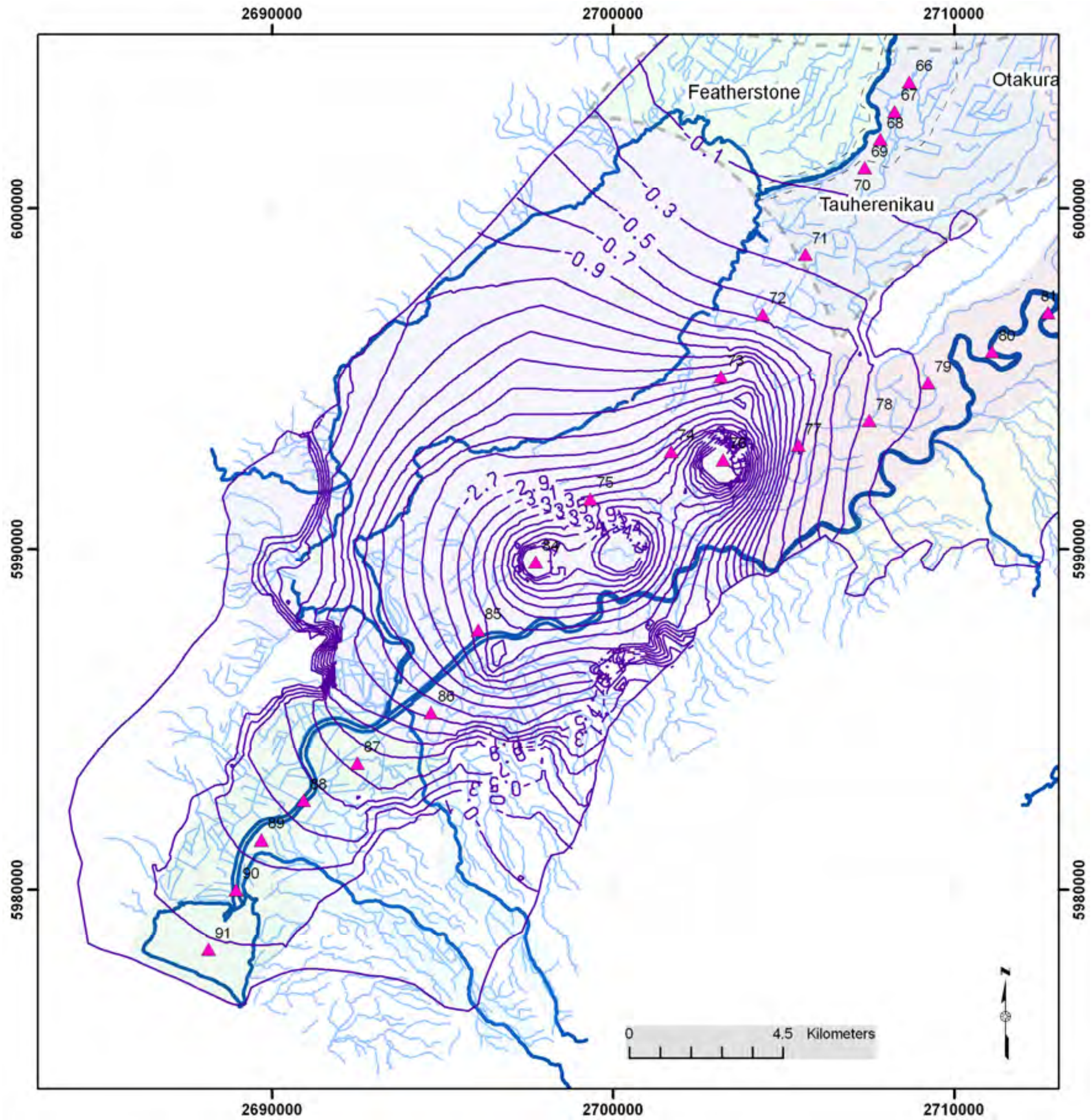

Figure F8: Simulated drawdowns in the confined Q2 aquifer associated with a combined abstraction of 25,000 m^3/day from 12 bores located in both the Q2 and Q4 aquifers. Output is for model day 5,698 (mid 2007/08 irrigation season). Drawdown contour interval is 0.2 m and the outermost contour denotes 0.1 m of drawdown. Pink numbered triangles are the head observation points used to construct Figure F9.

Figures F8 and F9 also show that the model predicts the extension of Lake zone drawdown effects into the Onoke area as far as the coast in the Q2 aquifer. The drawdown extends further downgradient towards the coast. A drawdown of 0.1 m in the Q2 confined aquifer is predicted beneath Lake Onoke. The drawdown in the Onoke zone results in a small enhanced throughflow northwards across the Onoke-Lake zone boundaries (see Section F.11 on the Onoke water management zone).

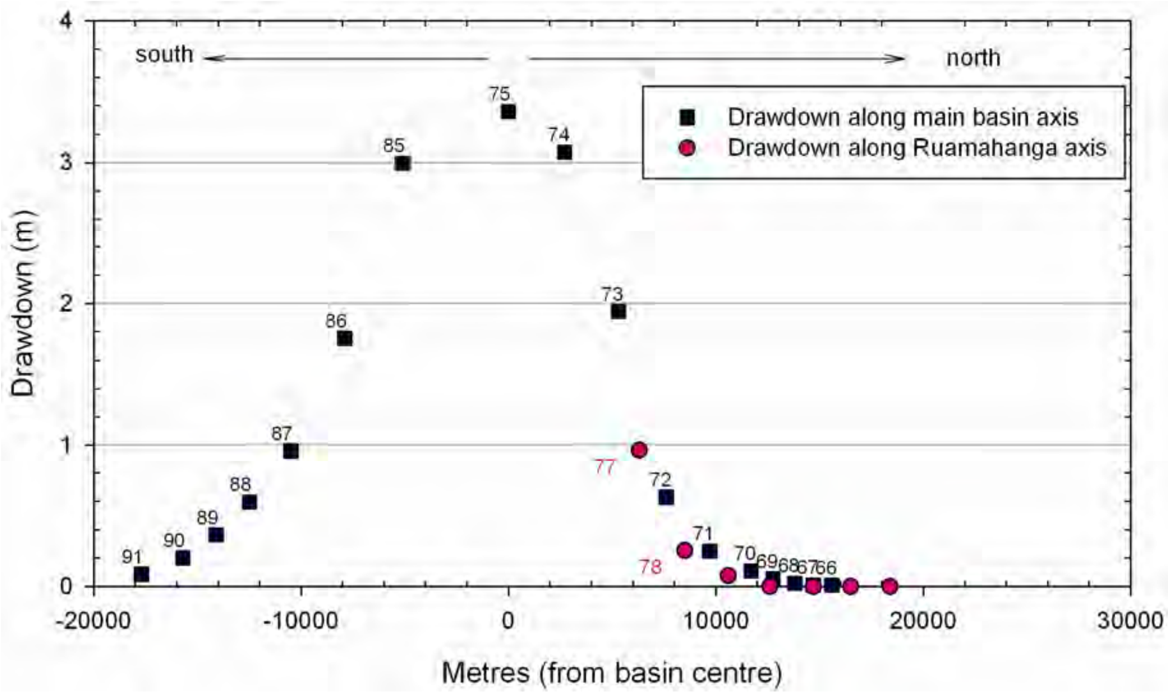

Figure F9: Simulated drawdowns along two axes through the Lake basin in the confined Q2 aquifer associated with a total abstraction of 25,000 m^3/day. The figure shows the shape of the 'cone of depression' which extends at a shallower angle down-gradient compared to the steep up-gradient profile. Numbered observation points are shown in Figure F8; Point 75 is the centre of the basin – positive meterage to the north and negative to the south of this point.

Surface water depletion assessment

The depletion effects resulting from Lake zone abstraction were assessed using two model scenarios:

Scenario 1: The existing (estimated) abstraction with all Lower Valley bores pumping for the 16-year transient model run (the calibrated model). This scenario enables the interactions between the zones to be examined when currently consented abstraction is occurring across the entire model domain.

Scenario 2: Only Lake zone bores pumping and a shortened run duration for the period 2 June 2004 to 1 October 2008 (four irrigation seasons). This scenario enables the effects of pumping from the Lake zone only to be isolated.

For both scenarios, the potential effects of abstraction on surface water and throughflow dynamics were estimated by comparing water balance outputs with the baseline (no-abstraction) simulation.

On the basis of the spatial drawdown patterns described earlier in this section, flux balances for the following surface water systems were extracted from the model for the abstraction and no-abstraction scenarios (note many of these are located in the recharge area of the confined Lake zone aquifers):

- Lake Wairarapa

- Ruamahanga River (Lake zone)
- Ruamahanga River (Lower Ruamahanga zone)
- Tauherenikau River
- Stonestead/Dock Creek
- Featherston springs

The depletion assessments are presented in Figures F10 to F15 for both scenarios.

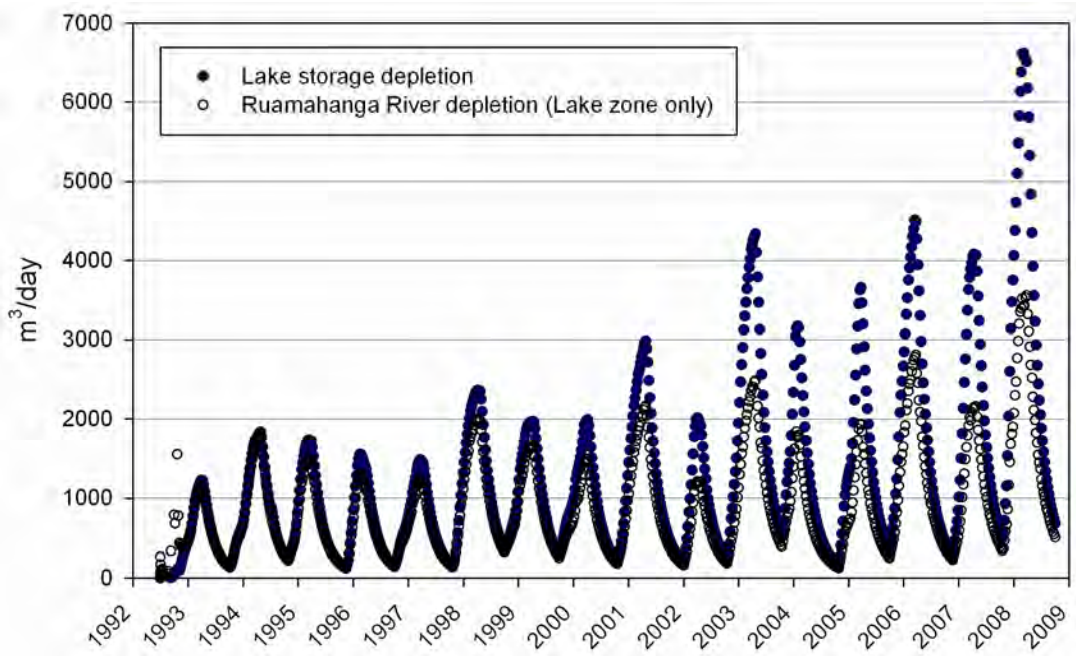

Figure F10: Scenario 1 – simulated depletion of Lake Wairarapa and the Ruamahanga River (within the Lake zone) – for the period 1992 to 2008 assuming abstraction from all zones

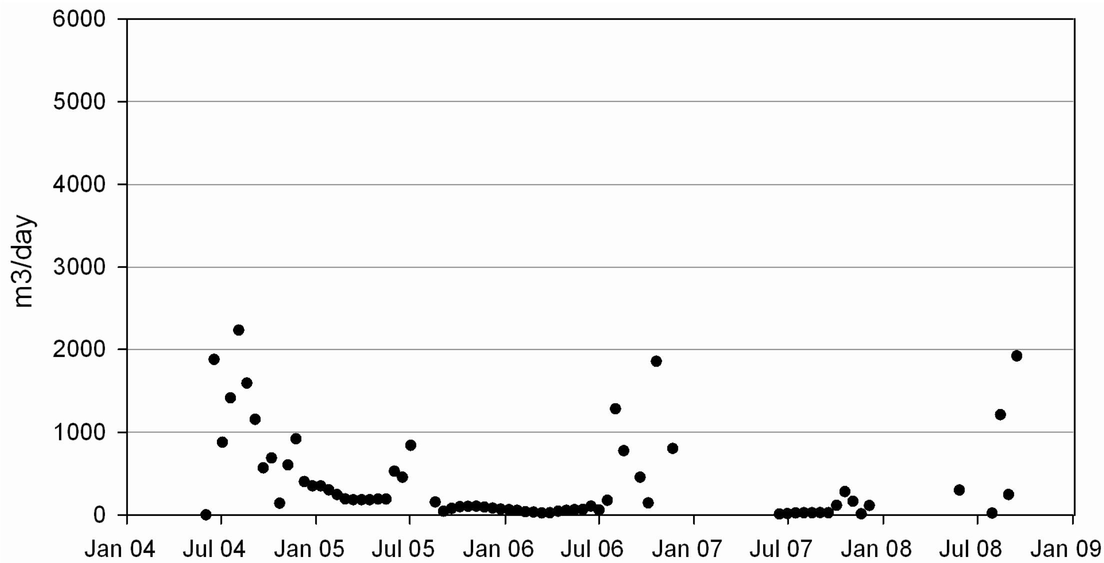

Figure F11: Scenario 2 – simulated depletion of the Tauherenikau River as a result of abstraction in the Lake zone only – for the period 2004 to 2008

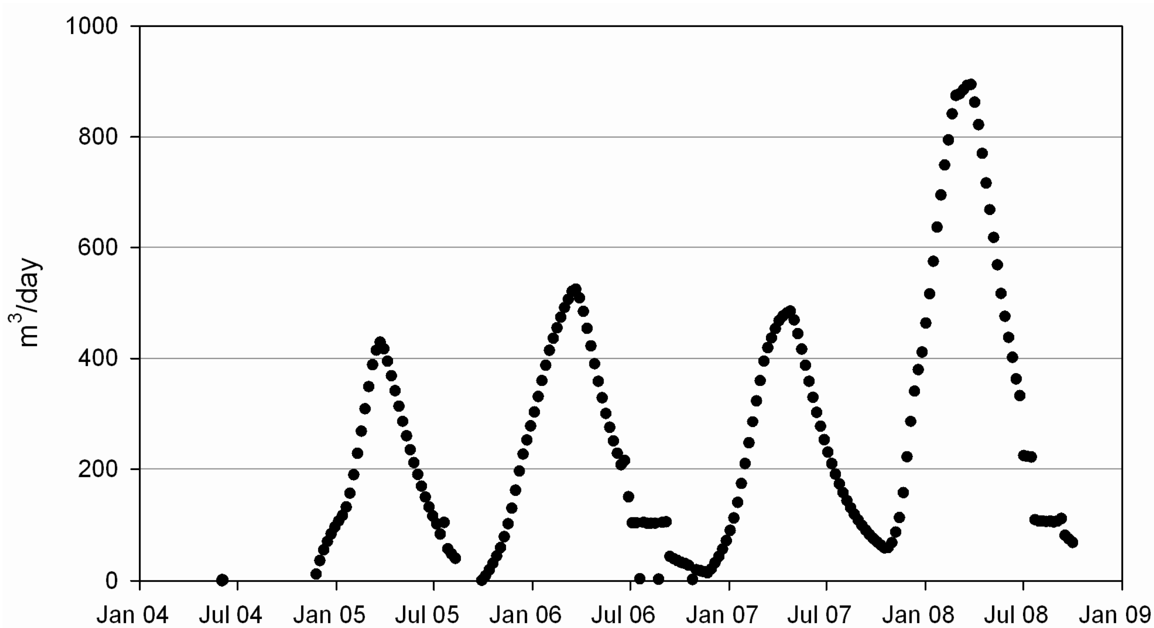

Figure F12: Scenario 2 – simulated depletion of Stonestead (Dock) Creek as a result of abstraction in the Lake zone only – for the period 2004 to 2008

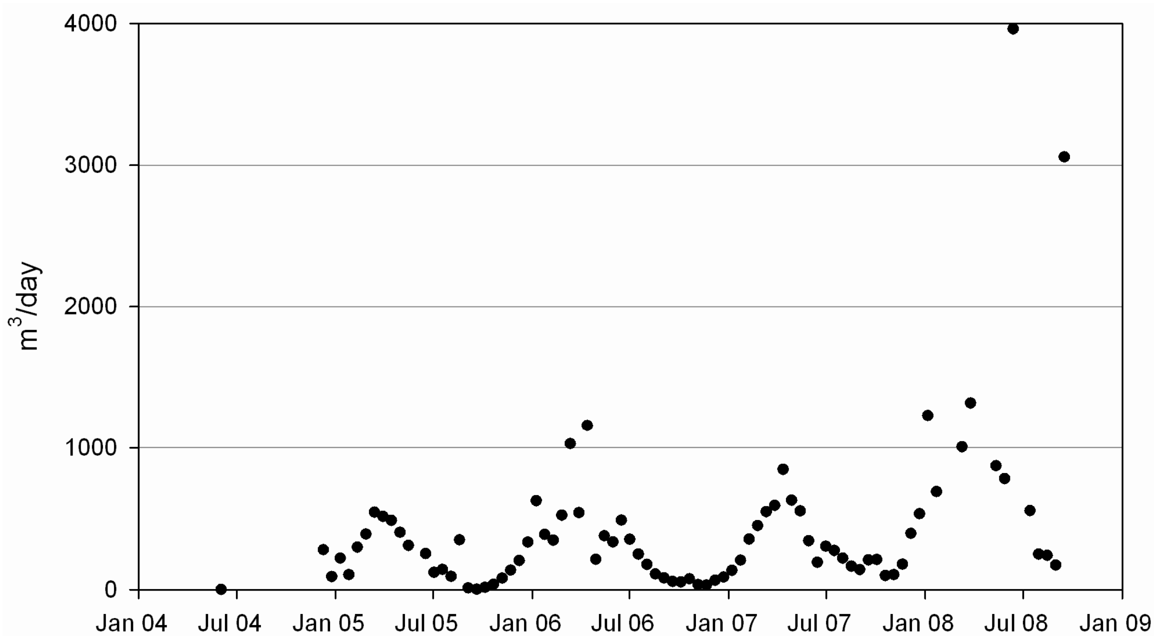

Figure F13: Scenario 2 – simulated depletion of the Featherston springs as a result of abstraction in the Lake zone only – for the period 2004 to 2008

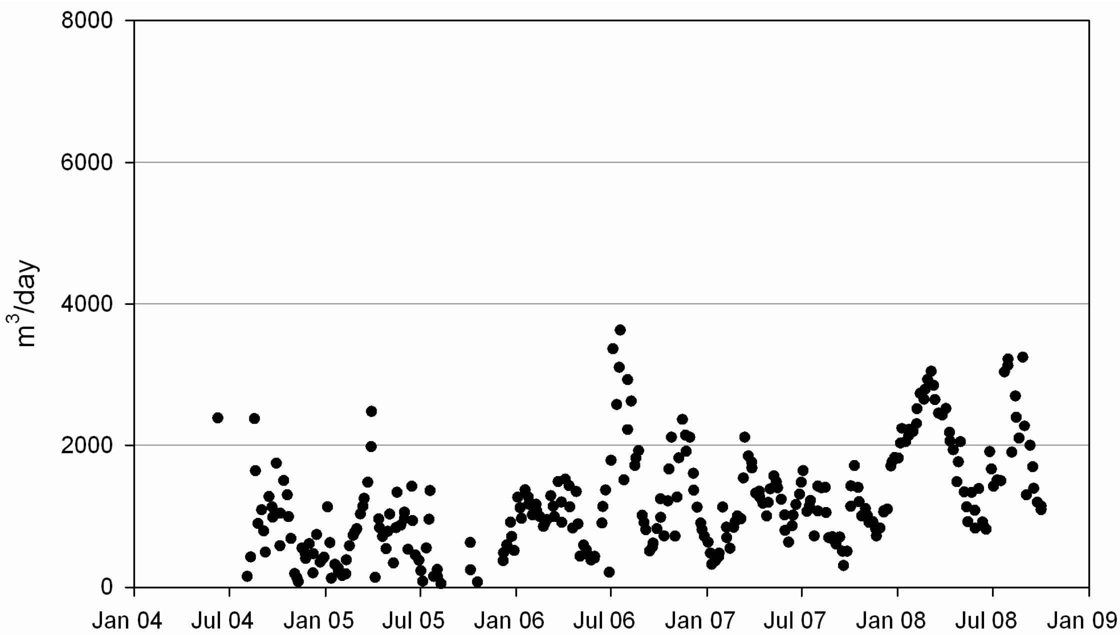

Figure F14: Scenario 2 – simulated depletion of the Ruamahanga River in the Lower Ruamahanga zone as a result of abstraction in the Lake zone only over the period 2004 to 2008

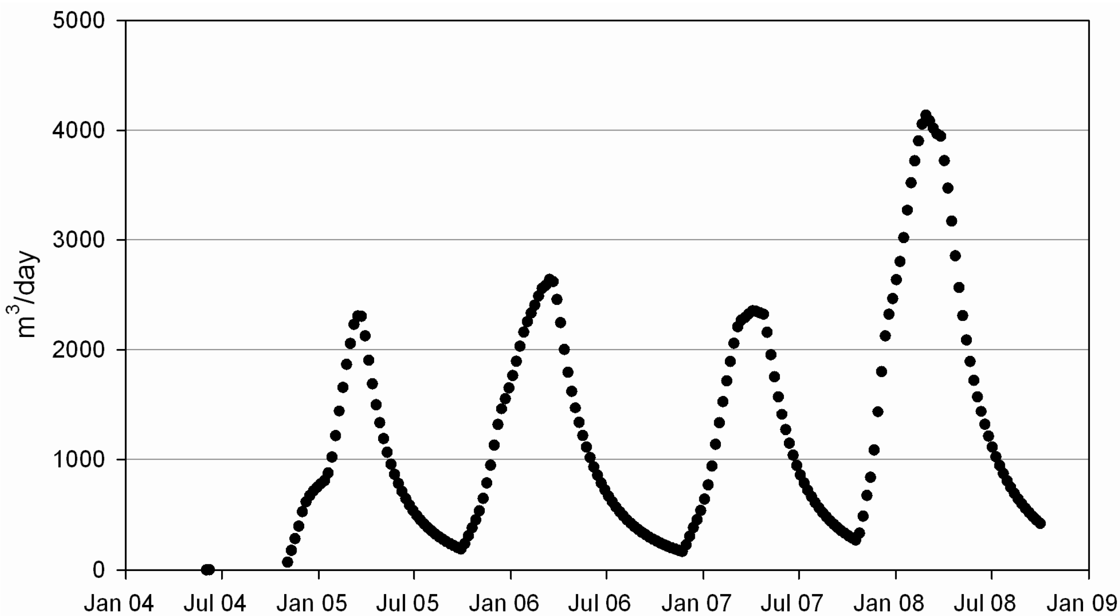

Figure F15: Scenario 2 – simulated depletion of Lake Wairarapa as a result of abstraction in the Lake zone only over the period 2004 to 2008

The total modelled depletion of Lake Wairarapa is shown in Figures F10 and F15. Scenario 1 (Figure F10) predicts a lake inflow depletion approximately 2,000 m^3/day higher during the 2007/08 irrigation season because this scenario also includes the effects of pumping from the neighbouring Tauherenikau zone. Approximately 65 to 70% of total lake depletion is caused by abstraction from the Lake zone confined aquifers. The Lake zone abstraction alone therefore results in a depletion effect on Lake Wairarapa of about 18% of the pumping rate (peak 2007/08 pumping rate is 23,000 m^3/day and the depletion is 4,200 m^3/day).

The Ruamahanga River is also sensitive to abstraction from the Lake zone. Figure F10 shows a seasonal depletion of approximately 3,500 m^3/day in the reach of the Ruamahanga River located within the Lake zone during the 2007/08 irrigation season. Figure F14 shows an additional depletion along the river reach located in the upstream Lower Ruamahanga zone of about 3,000 m^3/day (attributable to Lake zone abstraction only). A total depletion of 6,500 m^3/day is simulated as a result of Lake zone abstraction (2007/08) which peaked at 23,000 m^3/day. Calculated stream depletion in the Lower Ruamahanga zone resulting from abstraction in the Lake zone is therefore equivalent to approximately 28% of the total abstraction rate in the Lake zone.

Figures F11 to F13 depict the effects of Lake zone abstraction on the groundwater-surface water fluxes in the lower Tauherenikau fan. Although some numerical scatter is evident on Figure F11, it appears that the simulated abstraction has no significant effect on the Tauherenikau River. This is consistent with physical observations (from concurrent gauging data) in the lower reaches of this river which show limited interaction with groundwater below State Highway 53. The river seems to be largely isolated from the water table and its bed is perched above the surrounding land.

Figure F12 shows that Stonestead Creek is significantly influenced by abstraction in the Lake zone confined aquifers. Figure F8 demonstrates that small drawdowns from existing pumping extend into the headwater areas of Stonestead Creek and the Featherston springs resulting in a depletion of spring discharge (illustrated in Figure F12 and Figure F13). Both spring systems experienced a similar depletion of about 1,000 m^3/day each during the 2007/08 irrigation season (equivalent to about 8% of the Lake zone pumping rate).

Table F2 summarises the results of the scenario simulations which characterise the relationship between abstraction from Q2 and Q4 aquifers in the Lake zone and the impacts on surface water environments both within the zone and in upstream connected zones. Table F2 also shows the ratio of depletion (q) to pumping rate (Q), and the impact of depletion on low flows over the 2007/08 irrigation season.

The largest depletion effect is experienced by the Ruamahanga River, although Lake Wairarapa experiences the largest proportional depletion effect in relation to the magnitude of natural groundwater discharge (11% of 37,000 m^3/day). The total surface water depletion is equivalent to approximately 60% of the pumping rate.

The total lake depletion was calculated as the sum of direct lake depletion and the reduction in the spring flows on the Tauherenikau fan. This cumulative depletion effect is equivalent to about 27% of the pumping rate and is been estimated to be equivalent to about 4% of the estimated total summer lake inflow (approximately 150,000 m^3/day from groundwater and surface water[32]). Abstraction from the Tauherenikau and Featherston zones will also result in an additional depletion effect).

[32] Estimated lake water balance during low flow summer periods: groundwater discharge to lake (37,000m^3/day) + Stonestead flow (52,000 m^2/day) + Tauherenikau MALF (27,000 m^3/day) + Featherston springs + seepage drains (35,000 m^3/day) = approximately 150,000 m^3/day.

Table F2: Summary of modelled surface water depletion effects associated with abstraction from the Lake zone only during the 2007/08 irrigation season (peak abstraction rate = 23,000 m³/day from Q2 and Q3 aquifers)

	Depletion	q/Q	% of MALF or low flow/discharge
1. Lake Wairarapa (groundwater inflow depletion) Mean summer inflow: 0.43 m³/s	Depletion m³/day	q/Q	% of MALF, low flow or discharge
2. Ruamahanga River River in Lake zone River in Lower Ruamahanga zone Total Ruamahanga River within Lower Valley MALF: 11.8 m³/s (Pahautea reach)	4,200	0.18	11.3
3. Stonestead Creek MALF ~ 0.6 m³/s	 3,500 3,000 6,500	 0.15 0.13 0.28	 5.5
4. Featherston springs MALF: Not quantified	900	0.04	2.0
5. Tauherenikau River MALF at Lake: 0.31 m³/s (7-day)	1,000	0.04	Not quantified
Total surface water depletion effect	0	0	0
Total depletion of Lake Wairarapa (1+3+4) (estimated total lake inflow sw+gw=1.7m³/sec)	12,600	0.55	4.0[33]

Pumping-induced throughflow enhancement

The drawdown resulting from seasonal abstraction in the Lake zone (described above) extends across the up-gradient Lake zone boundaries into the Tauherenikau and Lower Ruamahanga zones. A consequence of drawdown propagation into these areas is the enhancement of throughflow into the Lake zone. Figure F16 shows the predicted increases in throughflow to the confined Lake zone aquifers as a result of seasonal abstraction (when there is no abstraction from the adjacent zones). It is interesting to note that although the Ruamahanga valley provides minimal throughflow under natural conditions (see Figure F5), when the confined Lake zone aquifers are pumped, most of the additional throughflow is induced from this area. During the 2007/08 irrigation season, about 2,700 m³/day of throughflow was induced from the Lower Ruamahanga zone which resulted in depletion of the river by a similar quantity (see Figure F14). The increase in throughflow from the Tauheranikau zone is similarly reflected by the combined depletion of the Stonestead Creek and Featherston springs of about 2,000 m³/day.

The throughflow enhancement from both the Lower Ruamahanga and Tauherenikau zones as a result of Lake zone abstraction can be regarded as an abstraction from these

33 Estimated lake water balance is approximately 150,000 m³/day.

zones which should be taken into account when assessing total groundwater allocation for neighbouring water management zones.

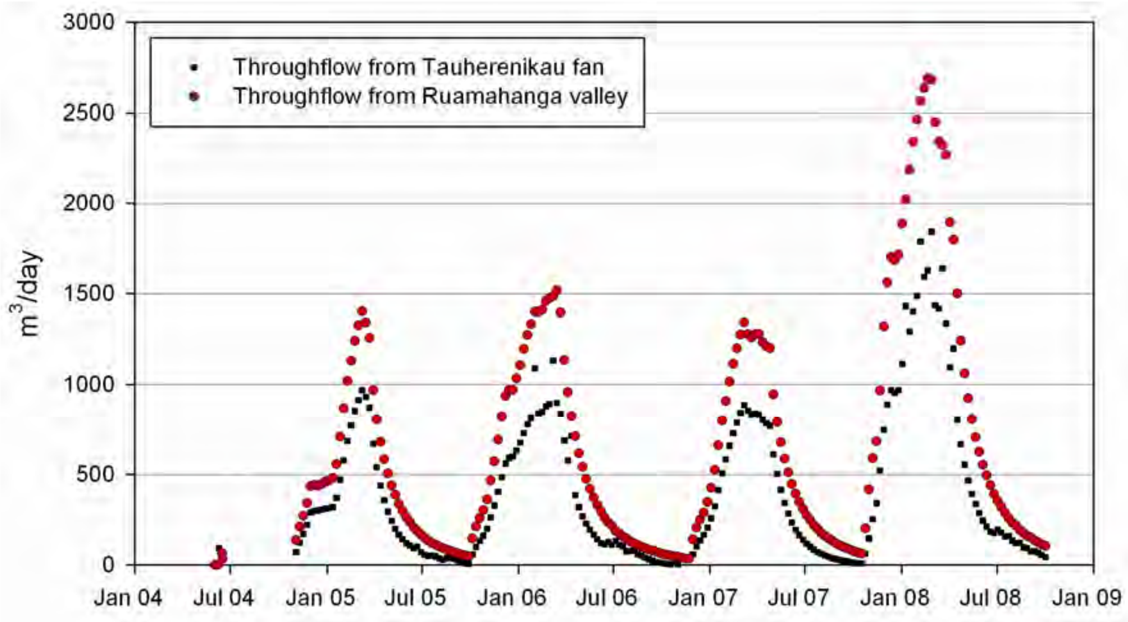

Figure F16: Simulated increases in aquifer throughflow to the confined Lake zone aquifers during abstraction within the zone. More additional water is drawn from the Ruamahanga valley (Lower Ruamahanga zone) than from the Tauherenikau fan. During the 2007/08 irrigation season the increased throughflow from the Ruamahanga valley was about 12% of the pumping rate; for the Tauherenikau fan it was about 8% of the pumping rate.

F.4.6 Groundwater allocation options for the Lake zone

Groundwater-surface water interaction zones

- Due to the presence of the Lake, Ruamahanga River and numerous wetlands, the very shallow groundwater environment of the Lake zone should be classified as Category B to a depth of 15 m. This will allow local stream depletion effects from abstraction close to rivers, streams and wetlands to be actively managed where there is a high or direct hydraulic connection.
- The confined aquifers (>20 m) should have a Category C designation.

Groundwater allocation

The Lake zone groundwater system exhibits a clear hydraulic connection with the neighbouring Tauherenikau and Lower Ruamahanga zones. These up-gradient zones comprise the recharge areas for the confined lake basin aquifers. Numerical modelling also indicates that the confined lake basin aquifers discharge into Lake Wairarapa and into the lower reaches of the Ruamahanga River. These characteristics mean that drawdowns resulting from abstraction in confined Lake zone aquifers have potential to affect the surface water environment both within the zone by reducing groundwater discharge rates, and in neighbouring zones by inducing additional throughflow recharge into the confined system.

Groundwater modelling has enabled quantification of the depletion effects of Lake zone abstraction on connected surface water environments. The simulations predict that abstraction from the confined aquifers results in a significant reduction in groundwater discharge into Lake Wairarapa (both vertical leakage and lateral throughflow around the Tauherenikau delta area). Currently, the reduction in groundwater discharge to the lake appears to be about 11% of the estimated natural summer discharge rate into the lake of 37,000 m^3/day (2007/08 irrigation season). Depletion of other surface water environments has a relatively minor influence on the low flows of these systems (refer to Table F2).

- It is appropriate that an allocation limit for the Lake zone confined aquifers be referenced to the depletion effect on Lake Wairarapa. Such an approach will also ensure that effects on other connected surface water environments remain minimal, and that drawdown within the confined aquifers is managed. The numerical model has characterised the lake depletion factor to be 18% of the Lake zone abstraction rate (q/Q = 0.18).

- There are two developed confined aquifers in the Lake zone (Q2 and Q4). Allocation policies should incorporate all confined aquifers in the zone as a single hydraulic unit.

- The induced recharge (and resultant surface water depletion) from the neighbouring Tauherenikau (semi-confined and unconfined) and Lower Ruamahanga zones should be taken into consideration in the allocation of groundwater from these zones. The numerical model has characterised the induced throughflow/depletion effect on adjacent zones as a proportion of Lake zone abstraction (Table F2):

Tauherenikau zone:	Lake zone daily abstraction x 0.08
Lower Ruamahanga zone:	Lake zone daily abstraction x 0.13

- The confined Lake zone aquifers do not have an immediate connection to surface water recharge sources. There is also significant seasonal storage depletion from the groundwater system of about 70% of the pumping volume (see Figure F7). The annual allocation quantity should be based upon a pumping duration of 180 days (six months) to ensure the aquifer recovers seasonally.

- The interference effects from abstraction in the Tauherenikau zone on Lake Wairarapa groundwater discharge should be taken into consideration when calculating allocation for the Lake zone. This effect has been calculated to be 0.07 x Tauherenikau zone daily abstraction. A Tauherenikau zone abstraction of52,200 m^3/day has been recommended (therefore, the additional effect on Lake Wairarapa would be about 3,700 m^3/day).

Potential options for groundwater allocation in the Lake water management zone based on the depletion effect on natural discharge to Lake Wairarapa are outlined in Table F3. Of these, Option 3 is recommended which represents a 25% reduction in the total groundwater inflow to Lake Wairarapa (this includes the effect from the neighbouring Tauherenikau Zone). The high drawdowns in the confined aquifers and growing understanding of the lake water balance are consistent with this recommendation. Option 3 represents a depletion of about 5% of the extimated total lake inflow (150,000m^3/day).

Table F3: Allocation options for the Lake water management zone based upon a depletion ratio (q/Q) for Lake Wairarapa of 0.18. Natural discharge to Lake Wairarapa is assumed to be 37,000 m^3/day. Interference depletion from the Tauherenikau zone is based upon an abstraction rate of 35,400 m^3/day and q/Q = 0.07 (see Section F.5).

Options	A Depletion effect (% of total GW discharge to lake)	B Depletion total (m^3/day)	C Interference depletion from Tauherenikau zone (m^3/day)	D Depletion balance (m^3/day)	E Daily allocation q/Q = 0.18 (m^3/day)	F Annual allocation (m^3 x 10^6/year)
1	Option 1: 15%	5,550	2,500	3,050	17,000	3.05
2	Option 2: 20%	7,400	2,500	4,900	27,200	4.9
3	Option 3: 25%	9,250	2,500	6,750	37,500	6.75

Explanation of Table:
A: percent depletion of groundwater discharge to Lake (modelled to be about 37,000m^3/day)
B: A * 37,000
C: Interference effect from pumping in the Rauherenikau Zone (assuming Option 1 is adopted: 35,400 * 0.07 = c. 2,500)
D: B - C
E: D / 0.18
F: D * 180

Current allocation from 12 bores located in the Lake zone (all aquifers) stands at 36,000 m^3/day (6.41 Mm^3/year), although daily actual use was estimated to be about 75% of this over the 2007/08 irrigation season (based on metering).

F.5 Tauherenikau water management zone

F.5.1 Overview

Zone delineation: The Tauherenikau water management zone incorporates the Tauherenikau alluvial fan system between the Wairarapa Fault and Te Maire ridge (Figure F17).

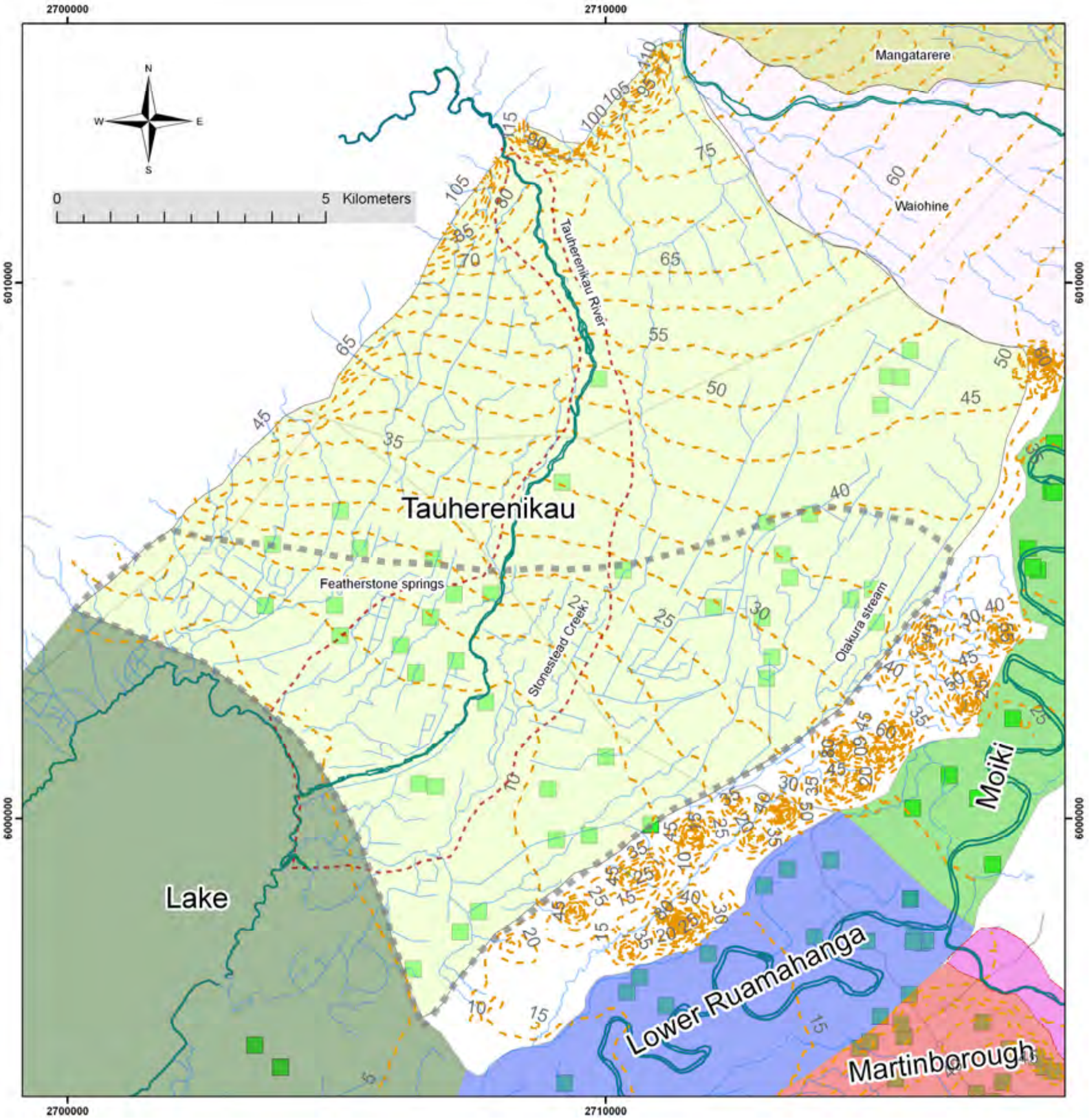

Figure F17: The Tauherenikau water management zone showing existing groundwater bores with consented abstraction (green squares), groundwater flow contours (orange dashed lines, contours at 5 m intervals – southern boundary follows 5 m contour line), and the extent of the aquifer system classified as Category A (direct hydraulic connection) – red dashed line around the Tauherenikau River). Also shown is the approximate extent of semi-confined aquifers which continue beneath Lake Wairarapa where they become confined (thick grey dashed line). Most existing bores abstract from the semi-confined aquifers (known in the existing RFP (WRC 1999) as the Kahutara and Battersea zones).

Area: The zone covers an area of 152 km^2 of which the semi-confined aquifers occupy about 70 km^2.

Zone boundaries: The southern boundary is coincident with a transition zone between the Tauherenikau fan unconfined and semi-confined aquifers and the deep Lake basin confined aquifers. It is approximately aligned with the northern margin of Lake Wairarapa and extends to the end of Te Maire ridge. Groundwater throughflow occurs across this boundary from the Tauherenikau zone, either directly into the Lake Wairarapa or the deeper confined aquifers in the Lake zone.

Both the western and eastern boundaries are geologically defined by the contact between late Quaternary alluvium and basement rock or older low permeability sequences. The western boundary is aligned with the Wairarapa Fault and the eastern boundary follows the edge of Te Maire ridge.

The northern boundary follows the edge of the prominent terrace feature which marks the flow divide between the Waiohine zone to the north, and the Tauherenikau zone to the south.

Principal surface water systems: Tauherenikau River, Otukura Stream, Stonestead Creek (also known as Dock Creek), 'Featherston springs' (Abbotts Creek, Donalds Creek, numerous small channels).

Aquifer sequences: Unconfined in the north, becoming semi-confined aquifers towards the Lake Basin margin.

Recharge: Estimated average annual rainfall recharge in the Tauherenikau zone is 3.6 x 10^7 m^3 (9,900 m^3/day).

Existing RFP zones: Woodside, Tauherenikau, Kahutara (north end only), Lake Domain, Battersea. Table F4 shows the existing allocation status of these zones.

Table F4: 'Safe yield' estimates and current groundwater allocation status for existing RFP (WRC 1999) groundwater zones located in (or partially within) in the Tauherenikau water management zone. Note zones marked (*) cross into the Lake zone.

Existing RFP zone	'Safe yield' (10^6 m^3/year)	Allocation (m^3/day)	% allocated	Number of bores
Woodside	16.0	3,415	4	7
Tauherenikau	20.0	28,145	25	13
Kahutara*	(LV)	26,011	48 – 100	12
Battersea	2.4	8,382	77	9
Lake Domain*	(LV)	8,208	48 – 100	3

F.5.2 Current allocation from the Tauherenikau water management zone

As at June 2010, consented groundwater allocation from the Tauherenikau water management zone (as defined in Figure F17) was 56,900 m^3/day from 38 bores. Consented abstractions from the semi-confined aquifers amount to 34,400 m^3/day (20 bores). Total allocation outside the Category A classification (i.e. confined and unconfined abstraction) represents approximately 70% of the current allocation from the Tauherenikau water management zone.

F.5.3 Hydrogeology summary

The Tauherenikau fan complex takes the form of a wedge of heterogeneous fluvial and glacial outwash sediments deposited during late Quaternary glacial periods. The fan progrades towards Te Maire ridge and into the Lake basin. The alluvium is poorly sorted coarse matrix-rich gravel, becoming quite compact and matrix-bound with depth. The upper 40 m or so of the fan deposits is considered to be of Q2 to Q4 age (last glacial outwash gravels), and mapped as Q2 age at the surface, except in the vicinity of the Tauherenikau River and adjacent to Te Maire ridge where Q1 deposits are mapped. Older glacial and interglacial deposits are interpreted to occur to a depth of about 60 to 70 m. Each major cold-climate phase is assumed to have accumulated in the order of 10 to 15 m of outwash fan gravels. Interglacial warm periods (Q1, Q3, Q5, Q7) are associated with marine/lacustrine silt/clay/peat-rich deposits which form laterally continuous aquitards toward southern margin of the Tauherenikau zone and extend southwards across the Lake Basin.

The northern ‘upper fan’ area closer to the Wairarapa Fault has a lower hydraulic conductivity. There also seems to be an absence of laterally traceable permeable zones in the fan sequence in this area, although local reworking is evident through the occurrence of sporadic occurrence of higher well yields. Generally, the groundwater resource potential in this area (north of the semi-confined area defined in Figure F17) tends to be poor.

In the more distal fan areas towards the Lake basin and against Te Maire ridge, progressive downstream reworking of the cold-phase (glacial) outwash gravels has resulted in the development of a moderately productive semi-confined aquifer sequence which sustains numerous higher-yielding bores (the Kahutara area). These bores abstract from Q6 deposits at depths of 30 to 50 m. However, most bores in the lower Tauherenikau fan area are screened in waterbearing intervals comprising last glacial Q2 or Q4 deposits (< c. 30 m deep). Near Te Maire ridge, the lateral continuity of the fan sequence has been influenced by complex structural deformation.

The fan sequence is therefore highly heterogeneous and is essentially a single leaky aquifer system. As it approaches the edge of the Lake basin, reworked cold-phase gravels with enhanced hydraulic conductivity begin to develop as individual water-bearing layers within the distal fan sequence. These progress into the Lake basin to form the confined aquifers.

Recharge occurs through a combination of rainfall infiltration and bed leakage from the Tauherenikau River. There is a prominent groundwater discharge zone around the lower part of the fan where numerous springs occur (Stonestead Creek, Otukura Stream and numerous springs in the Featherston and lake shore area). Discharge from the zone also occurs as throughflow to the deep Lake zone aquifers.

F.5.4 Hydrology summary

Tauherenikau River

The Tauherenikau River is the dominant drainage system in the zone. The river rises in the main Tararua Range near Mt Hector, and emerges onto the Wairarapa plain north of Featherston. It then flows across the alluvial plain to discharge into Lake Wairarapa. Keenan (2009) estimated the 7-day MALF at the river mouth (lake shore) to be 310 L/s (c. 27,000 m^3/day) compared to 1,317 L/s (113,800 m^3/day) at the gorge, just upstream of where the river emerges onto the plains. This downstream reduction in discharge is largely attributed to flow loss mostly in the middle reach between SH2 and SH53. There are no major tributaries to the river on the plains, and there is only one major abstraction – the Longwood Water Race.

Spring-fed streams

There are three major spring-fed stream systems in the Tauherenikau zone: Otukura/Battersea system, Stonestead Creek, and numerous springs in the Featherston area and lake shore (collectively referred to as the ‘Featherston springs’). Gyopari and McAlister (2010c; Figure 3.2) provide a map and more detailed description of the springs and wetlands on the Tauherenikau fan.

The Otukura Stream has a small lowland catchment abutting the western side of Te Maire ridge on the Tauherenikau alluvial fan. The naturalised 7-day mean annual low flow (MALF) estimate for the Otukura Stream, upstream of the Stonestead Creek confluence is 107 L/s (Watts 2007). However, it must be borne in mind that the flows are likely to be significantly influenced by inputs from the Moroa Water Race in summer. Groundwater modelling suggests that the mean groundwater baseflow discharge in this catchment is of the order of 25 L/s during summer.

Stonestead Creek is a tributary to the Otukura Stream and has quite different flow characteristics. This stream is sustained by a voluminous spring discharge derived from the adjacent Tauherenikau River via a shallow highly permeable aquifer. The mean low flow of the creek is estimated to be in the range of 600 to 700 L/s.

A system of drainage channels around the Featherston area are collectively termed the Donalds/Abbotts Creek system, or ‘Featherston springs’ in this report. There is relatively sparse information on this drainage system but some of the flows are regarded to be groundwater discharge from the fan alluvium. Spot gauging data suggest that the total summer baseflow in this stream system is in the order of 50 to 100 L/s.

F.5.5 Zone management objectives

The principal management objective in the Tauherenikau zone is to ensure the sustainable allocation of groundwater resources with respect to surface water ecosystems. The protection of the instream values of the Tauherenikau River and spring-fed steam systems on the lower parts of the fan (Stonestead, Featherston and Otukura systems) from the cumulative effects of groundwater abstraction and baseflow depletion is the primary criterion for developing sustainable allocation options in this zone. In addition, the effects of abstraction on groundwater discharge to Lake Wairarapa must also be considered.

Abstraction from this zone also affects throughflow to the down-gradient Lake zone aquifers as well as shallow-level throughflow discharge into Lake Wairarapa. As a result, the interaction between the two zones in response to abstraction needs to be considered when developing an allocation strategy for Tauherenikau water management zone.

F.5.6 Numerical modelling

The numerical groundwater flow model for the Lower Valley catchment was used to assess the sustainability of current groundwater abstractions and to develop allocation options for the Tauherenikau groundwater management zone. Full details of the model and the calibration process are provided by Gyopari and McAlister (2010c). The model has been principally used to evaluate the cumulative effects of abstraction on the surface water environment to assist in developing allocation options for takes outside the area classified as Category A (direct hydraulic connectivity).

Zone water balance

The numerical groundwater flow model has enabled a temporal characterisation of the natural water balance for the Tauherenikau zone using a version of the 16-year calibration simulation (1992 to 2008) which has no groundwater abstraction. This scenario provides a baseline simulation against which the effects of abstraction can be evaluated (by comparing the no-abstraction and abstraction scenarios). Of particular relevance to assessing the sustainability of abstraction, the model enables quantitative assessment of the potential cumulative depletion effects resulting from groundwater pumping on the surface water environment in the Tauherenikau (and adjacent) water management zone.

The principal water balance components for the Tauherenikau zone are rainfall recharge, surface water/groundwater fluxes, and groundwater throughflow into the Lake zone. Figure F18 shows the modelled annual rainfall recharge for the Tauherenikau zone for the period 1992 to 2007. The average annual rainfall recharge for this period is 36 x 10^6 m^3 (or approximately 98,000 m^3/day) and the lower quartile annual recharge is 26.4 x 10^6 m^3.

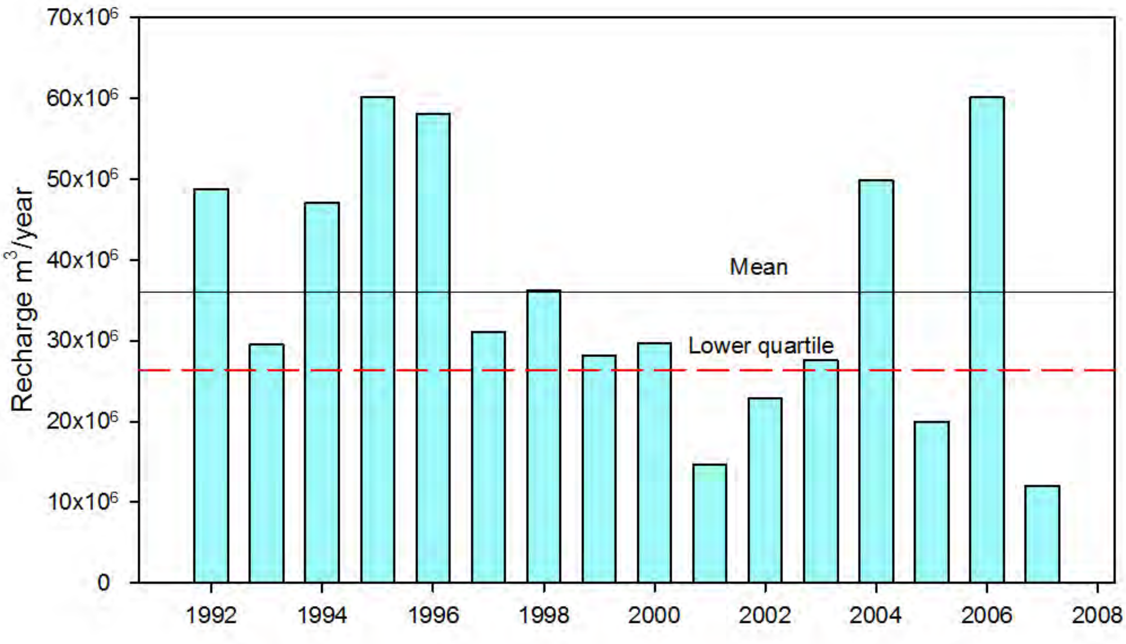

Figure F18: Modelled annual rainfall recharge (1992-2007) for the Tauherenikau zone (mean annual recharge is 36 x 10^6 m^3 and lower quartile annual recharge is 26.4 x 10^6 m^3)

Figure F19 shows the simulated groundwater flux to surface water (rivers, streams and springs) in the Tauherenikau zone. Since about 2000, the net flux has notably decreased during the summer. This change is largely attributed to the declining long-term rainfall recharge trend evident in recent years (as shown in Figure F18). Modelled summer discharge is, on average 90,000 m^3/day (1,04 m^3/s).

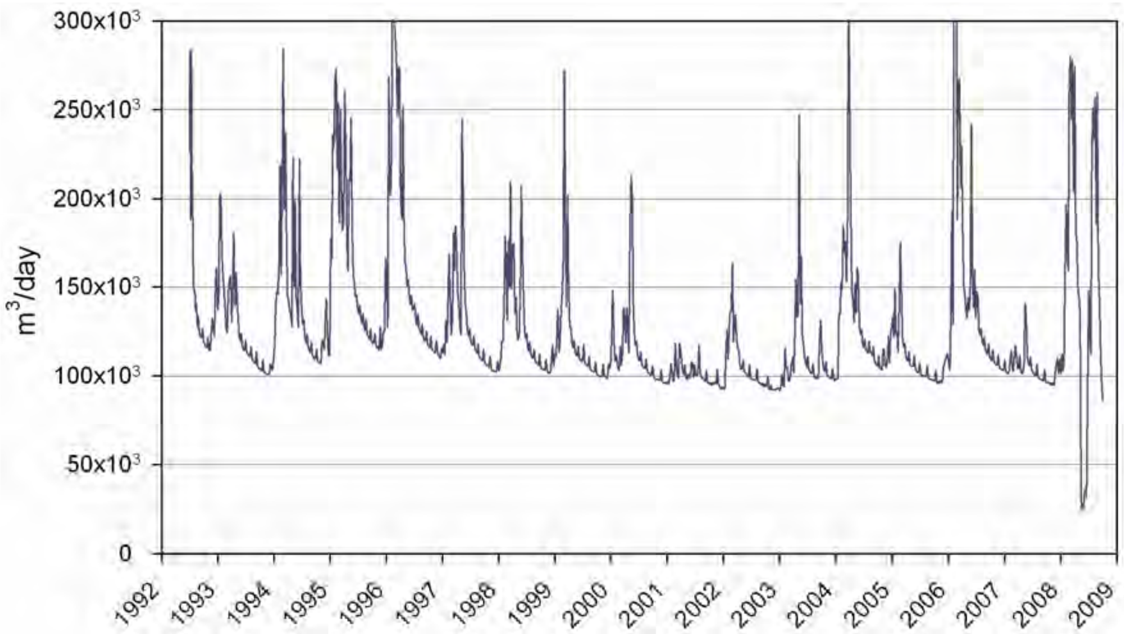

Figure F19: Simulated groundwater discharge to surface water (all streams and spring-fed tributaries) when in the Tauherenikau zone assuming no groundwater abstraction for the period 1992 to 2008

The Tauherenikau River loses flow to groundwater along its entire length between the Tararua foothills and Lake Wairarapa, with concurrent gauging indicating a majority of the loss occurs upstream of the SH53 Bridge. Figure F20 shows the simulated flow loss from the river when there is no groundwater abstraction. These data indicate a peak loss of about 85,000 m^3/day (approximately 1 m^3/s) during summer when the flow gradient between the river and water table is highest.

Abstraction from the Tauherenikau zone was simulated for the 16-year transient model run and is shown in Figure F21. Seasonal abstraction has increased significantly since about 2000 and now peaks at about 32,000 m^3/day from 38 consented bores. The 2007/08 season abstraction is largely based upon actual meter data whereas earlier years have been estimated. The current consented abstraction in the zone is about 57,000 m^3/day and therefore peak daily use appears to be around 60% of the consented rate (although total seasonal abstraction may be less than 40% of the total allocated volume).

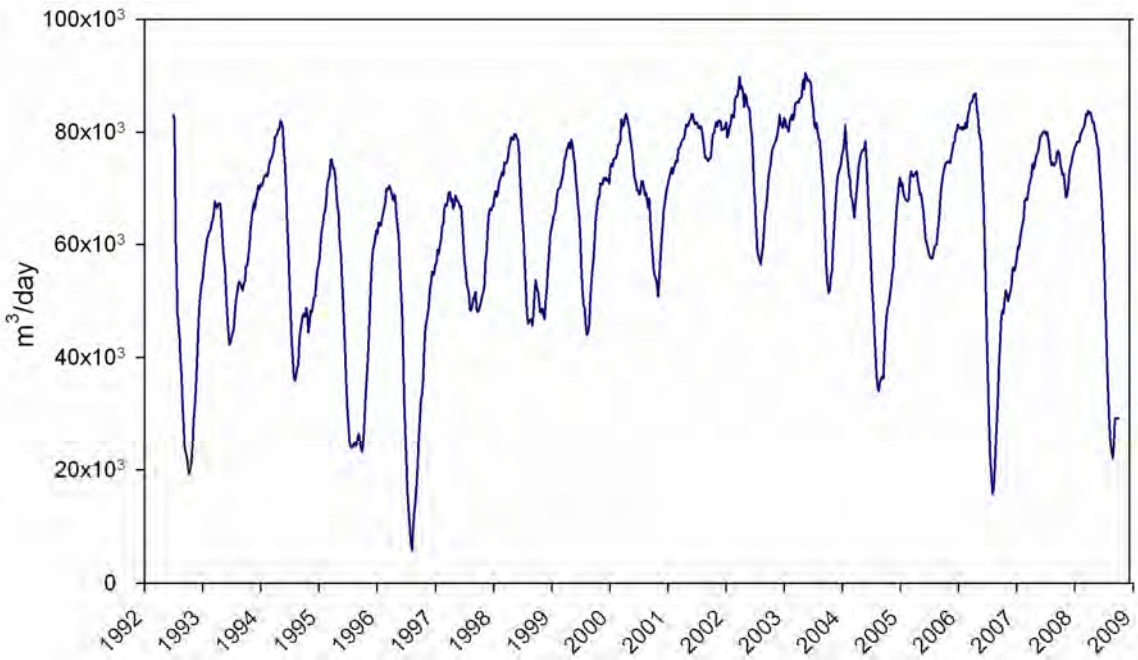

Figure F20: Modelled flow loss from the Tauherenikau River for the period 1992 to 2008. Higher losses occur during summer due to the development of a steeper vertical hydraulic gradient as groundwater levels decline in late summer/autumn.

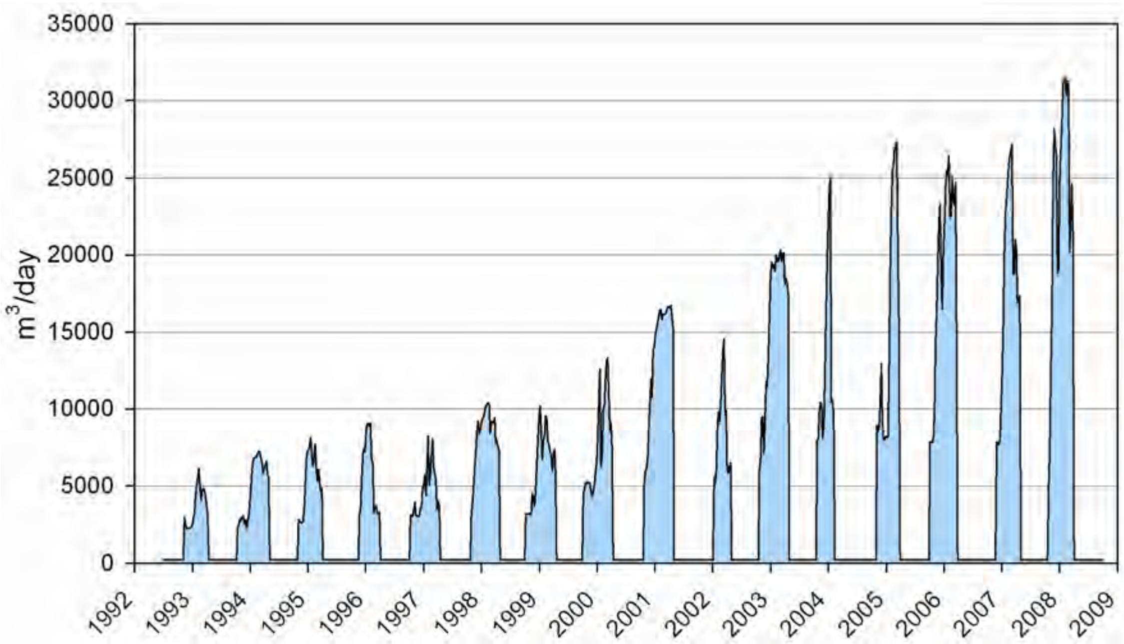

Figure F21: Simulated historic abstraction in the Tauherenikau zone of the Lower Valley catchment (1992 to 2008)

<u>Surface water and throughflow depletion assessment</u>

The depletion effects resulting from Tauherenikau zone abstraction were assessed using three model scenarios:

Scenario 1: Current (estimated) abstraction with all Lower Valley bores pumping for the 16-year transient model run (the calibrated model). In this scenario, all bores in the Lower Valley catchment are pumping and therefore cross-zone interference effects are present.

Scenario 2: A copy of the calibrated model in which only those bores in the Tauherenikau zone (but outside Category A) are pumping. The run duration is also shortened to 2 June 2004 to 1 October 2008 (four irrigation seasons). This scenario enables the effects associated with pumping only in the Tauherenikau zone to be isolated.

Scenario 3: As Scenario 2, but only bores located in the semi confined aquifer are pumping. This scenario isolates the effects of pumping from the deeper aquifers only.

For all scenarios, the water balance outputs were compared to baseline (no-abstraction) simulations so that the effects of abstraction on the surface water environment could be derived by comparing the two sets of water balance outputs. Flux balances for the following surface water systems were extracted from the model for the abstraction and no-abstraction scenarios (note many of these are located in the recharge area of the confined Lake zone aquifers):

- Tauherenikau River
- Stonestead Creek
- Featherston springs
- Otukura Stream
- Lake Wairarapa
- Throughflow from the Tauherenikau zone to the Lake zone

Scenario 1

The current (estimated) abstraction was simulated for the 16-year transient model run and the water balance outputs were compared to a baseline (no-abstraction) simulation. The effects of groundwater abstraction on the surface water environment were then quantified by comparing the two sets of water balance outputs. Figure F22 shows the simulated surface water depletion in the Tauherenikau zone together with the seasonal abstraction rates. During the final irrigation season of the simulation (2007/08), the depletion effect was about 20,000 m^3/day, which is approximately 62% of the abstraction rate.

Modelled stream depletion peaks towards the end of each irrigation season but does not cease when pumping is switched off; rather, there is a considerable lag shown by the slowly receding depletion into the winter months. Any regulation of pumping to control surface water depletion is unlikely to provide an effective means to mitigate stream depletion effects where there is a moderate to low degree of hydraulic connection due to the system lag and the necessity for storage to be replenished by winter recharge.

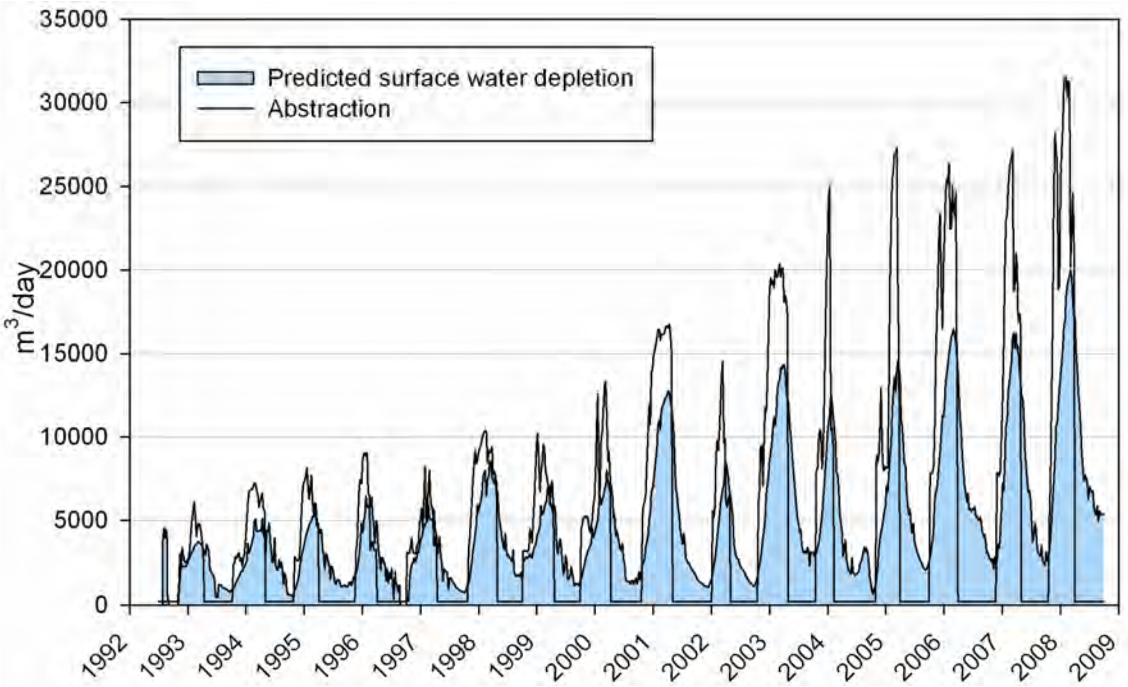

Figure F22: Simulated historic abstraction and associated surface water depletion in the Tauherenikau zone of the Lower Valley catchment (1992 to 2008). A depletion equivalent to 60% of the abstraction rate occurs within the timeframe of seasonal abstraction and recedes over the winter months.

Figure F23 shows the depletion effects of groundwater abstraction between 1992 and 2008 on individual surface water systems in the Tauherenikau zone. Almost half the total zone depletion occurs from the Stonestead Creek spring system and slightly less from the Featherston springs. Together these spring discharge zones account for about 80% of the total zone depletion indicating they are highly sensitive to abstraction drawdowns, even from the semi-confined aquifers.

The calculated depletion effect of only about 2,000 m^3/day (23 L/s) suggests the Tauherenikau River is less sensitive to abstraction compared to the spring systems. This may be due to the losing nature of this river, which many in places may be perched above the groundwater level and consequently is less sensitive to aquifer drawdowns particularly when groundwater levels are lowest.

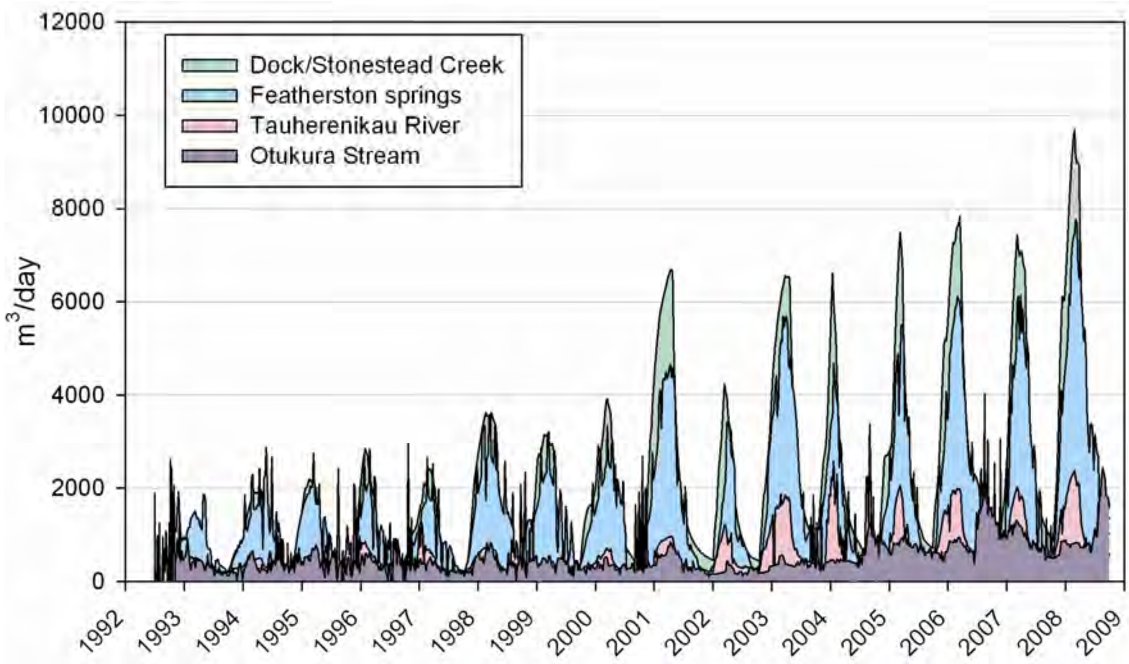

Figure F23: Simulated depletion in each surface water system in the Tauherenikau zone. The largest depletion occurs in the Stonestead Creek and Featherston springs systems which account for about 80% of the total depletion. The Tauherenikau River is relatively insensitive to abstraction effects.

Scenario 2

Scenario 2 is a short-run simulation (2004 to 2008) in which only bores in the Tauherenikau zone which are outside the Category A classification are pumping. Bores within Category A area were therefore omitted from this simulation which is concerned with the characterisation of the cumulative effects where there is less evidence for direct hydraulic connectivity. Figure F17 shows the extent of the Category A classification which is taken to be about 20 m deep (down to model slice 5), bores deeper than this within the underlying semi-confined aquifer are retained in this scenario.

Figure F24 shows the simulated depletion effects on the different surface water environments in the Tauherenikau zone, as well as on Lake Wairarapa in response to the seasonal pumping shown in Figure F25. The largest depletion effect occurs in Stonestead Creek reaching 7,000 m^3/day (80 L/s) during the 2007-08 irrigation season when the cumulative (daily) abstraction rate in the zone peaked at 25,000 m^3/day. The Featherston springs also modelled as experience a significant depletion effect of approximately 5,000 m^3/day (60 L/s) during the same irrigation season.

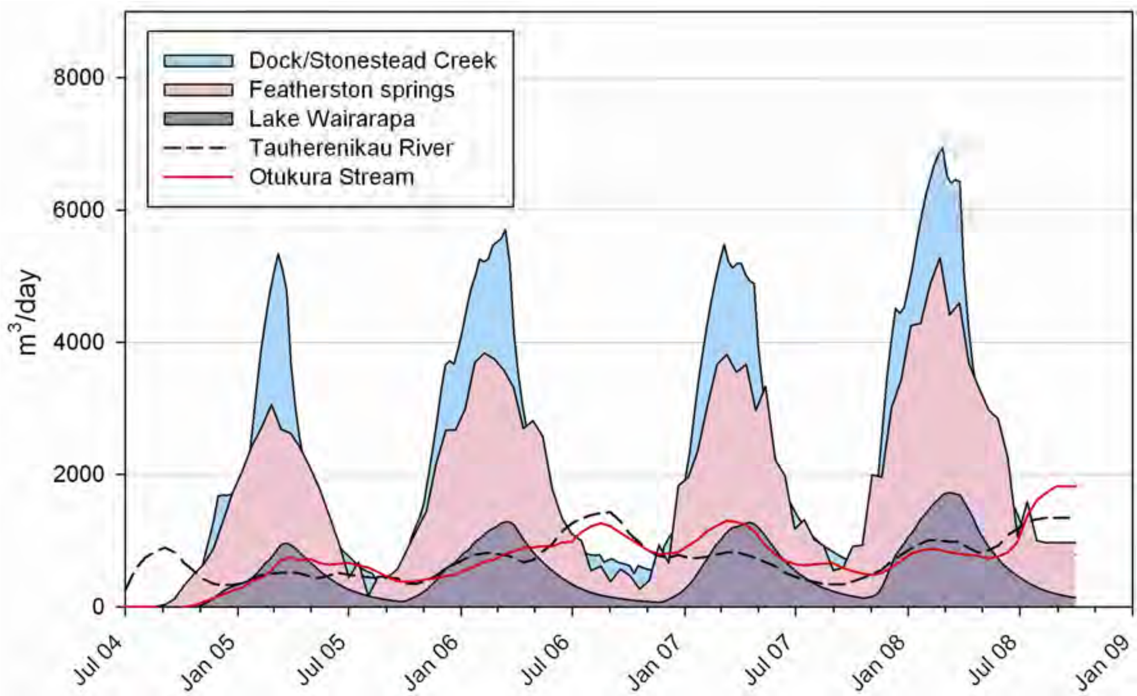

Figure F24: Scenario 2 depletion assessment – bores only in Tauherenikau zone pumping (excluding those within the Category A area)

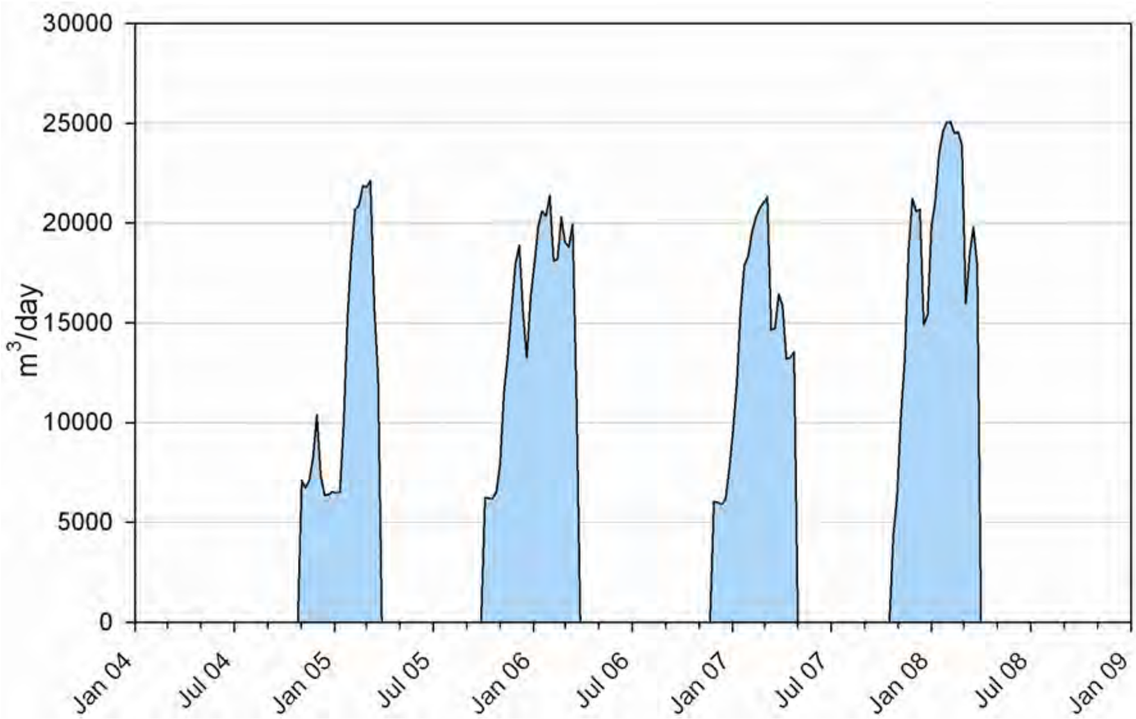

Figure F25: Scenario 2 modelled abstraction in the Tauherenikau zone (excluding bores in Category A less than 20 m deep)

In Scenario 2, groundwater discharge to Lake Wairarapa is also distinctly influenced by abstraction in the Tauherenikau zone with the calculated outflow reducing by up to 2,000 m^3/day during the 2007/08 irrigation season. This is also reflected in the reduction in throughflow to the Lake zone shown in Figure F26. However, in reality, abstraction from the Lake zone induces greater throughflow to offset this effect (see

Figure F16) so that when both zones are pumping there is little change in throughflow but an overall increase in drawdown.

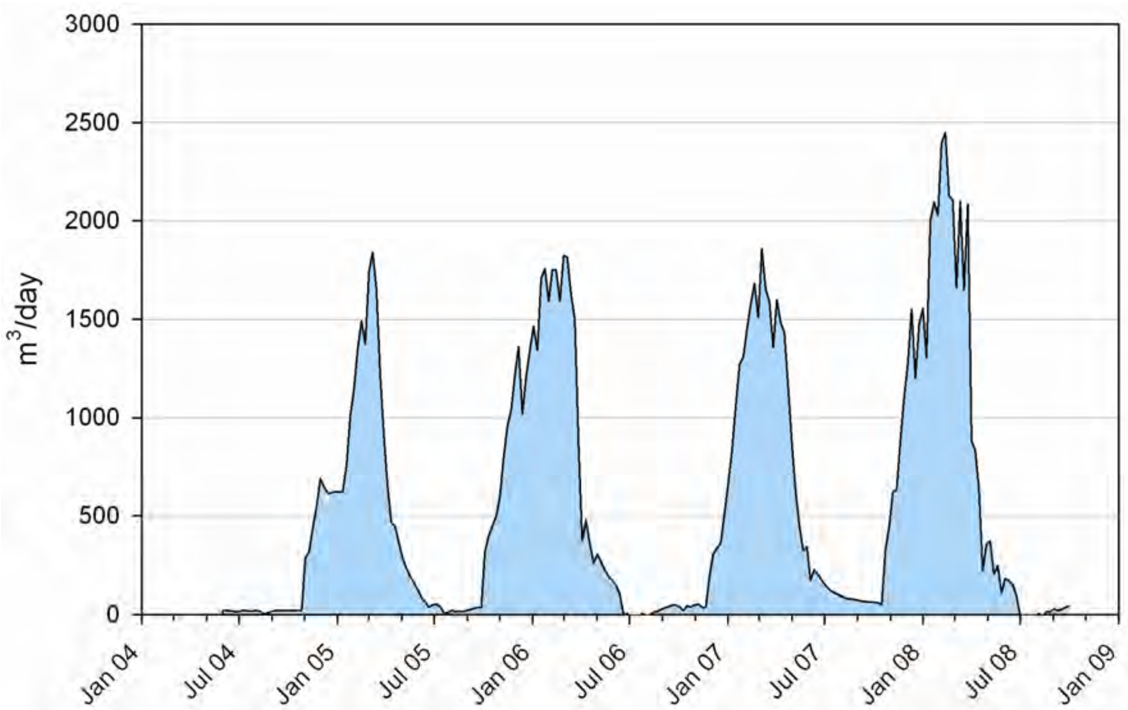

Figure F26: Scenario 2 – modelled reduction in throughflow from Tauherenikau to Lake zones measured across a vertical plane aligned with the southern edge of the Tauherenikau zone between Te Maire ridge and the Wairarapa Fault. In reality, when the Lake zone is pumped at the same time increased drawdowns propagate into the Tauherenikau zone to counter the effect of the reduced throughflow shown in the this plot (see Figure F16).

Scenario 3

Figures F27 to F29 show the modelled fluxes predicted by pumping Scenario 3 in which only those bores located in the semi-confined aquifer are pumping. There are 20 bores located in the semi-confined zone (delineated on Figure F17) pumping at a peak rate of about 22,000 m^3/day during the 2007/08 irrigation season. The results show that there is little difference in terms of depletion effects between Scenario 2 and Scenario 3 when the small change in pumping rate is considered. It is evident that most abstraction volumetrically occurs from the semi-confined aquifers and that surface water depletion effects and throughflow reductions to the Lake zone are primarily a response to abstraction from the semi-confined aquifer.

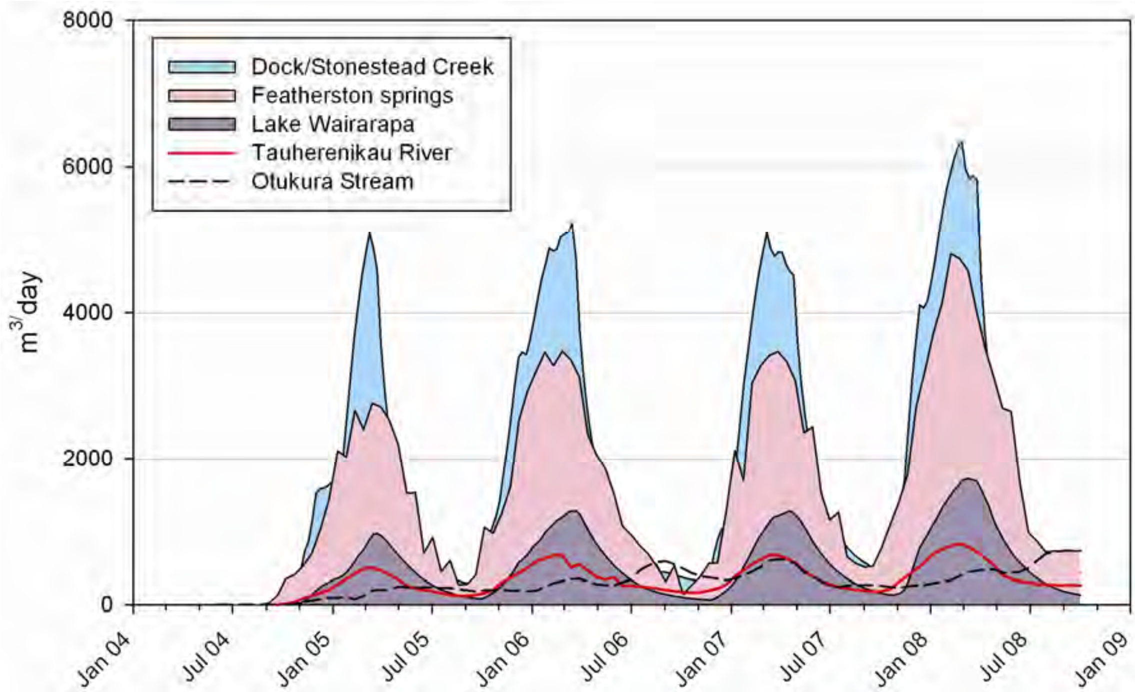

Figure F27: Scenario 3 – surface water depletion assessment. Only bores in Tauherenikau zone semi-confined aquifer pumping

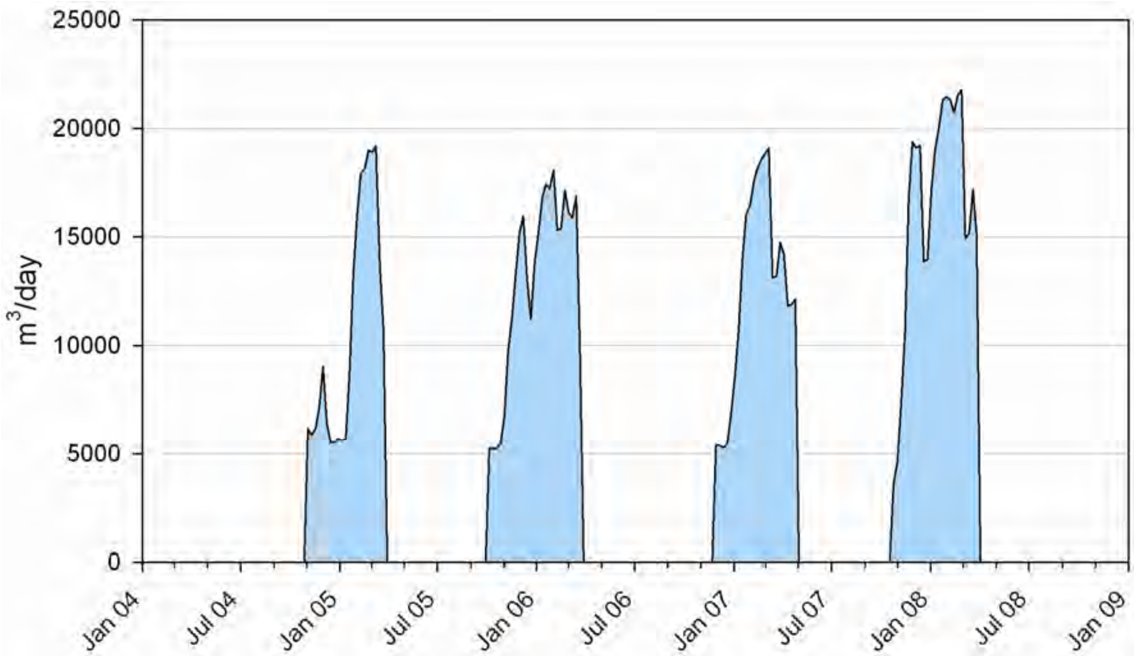

Figure F28: Scenario 3 – abstraction from semi-confined aquifers in the Tauherenikau zone only

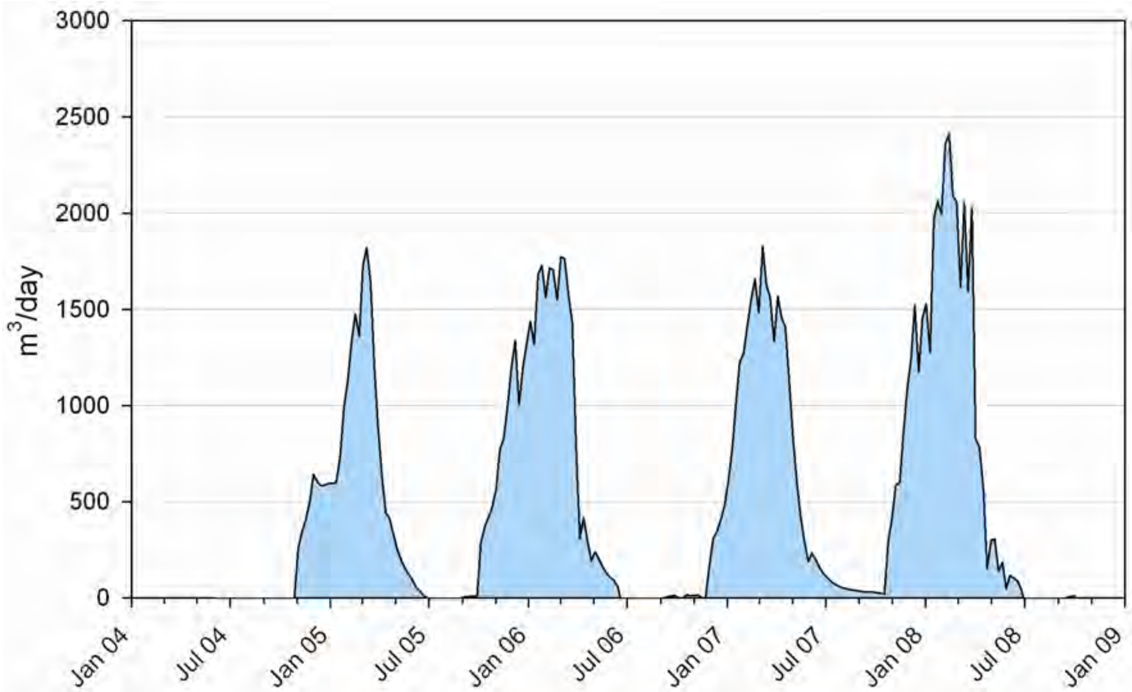

Figure F29: Scenario 3 – modelled reduction in throughflow from Tauherenikau to Lake zones measured across a vertical plane aligned with the southern edge of the Tauherenikau zone between Te Maire ridge and the Wairarapa Fault

Surface water depletion characterisation

Table F5 summarises scenarios 1 to 3 in terms of the impacts of abstraction on low flow conditions in each of the surface water environments. In the absence of sufficient monitoring data, the model has been used to characterise the natural low-flow fluxes to the spring systems (shown in Figures F30 to F33) in the absence of any groundwater abstraction.

Scenario 1 represents the magnitude of current effects when all abstractions bores in the Lower Valley catchment are pumping. Therefore the pumping effects from the adjacent Lake zone and bores located within the Category A (direct hydraulic connectivity zone) are also taken into account. Scenarios 2 and 3 serve to isolate the effects of abstraction from the Tauherenikau zone alone as a basis for determining allocation limits.

Abstraction patterns for all three scenarios do not result in significant effects on the Tauherenikau River (as previously discussed) where depletion appears to be in the order of 7% of its MALF. The spring discharge zones and Lake Wairarapa are considerably more sensitive to abstraction.

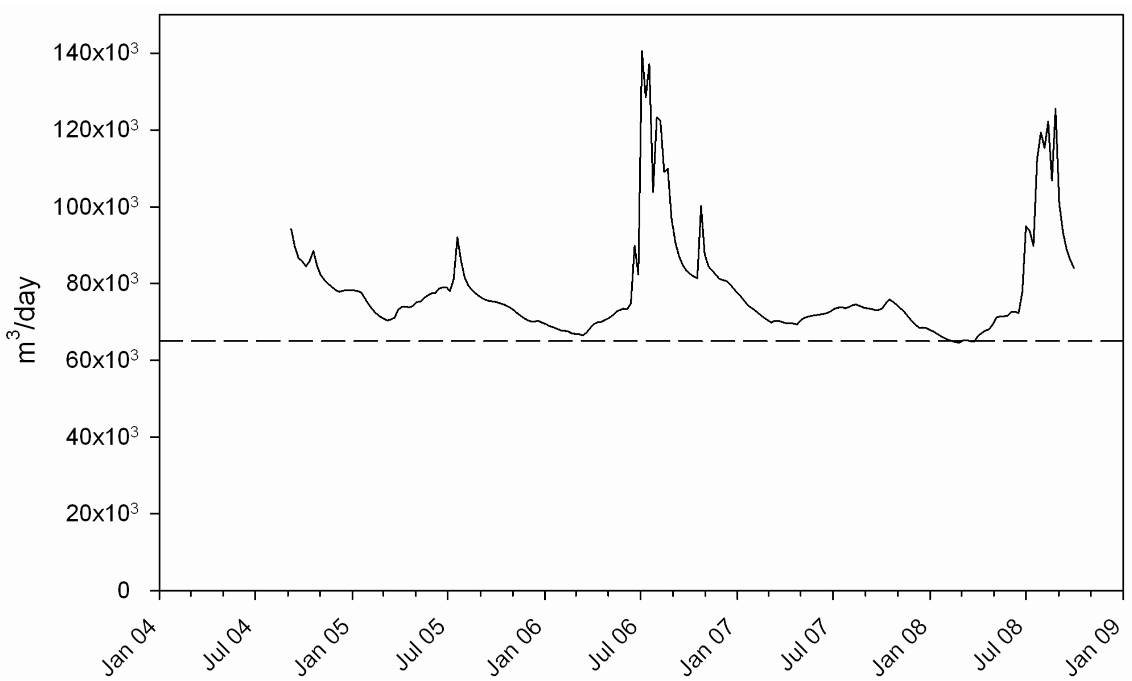

Figure F30: Simulated natural discharge to Stonestead (Dock) Creek when there is no groundwater abstraction. Mean low flow is about 65,000 m^3/day (750 L/s) and is indicated by the dashed line.

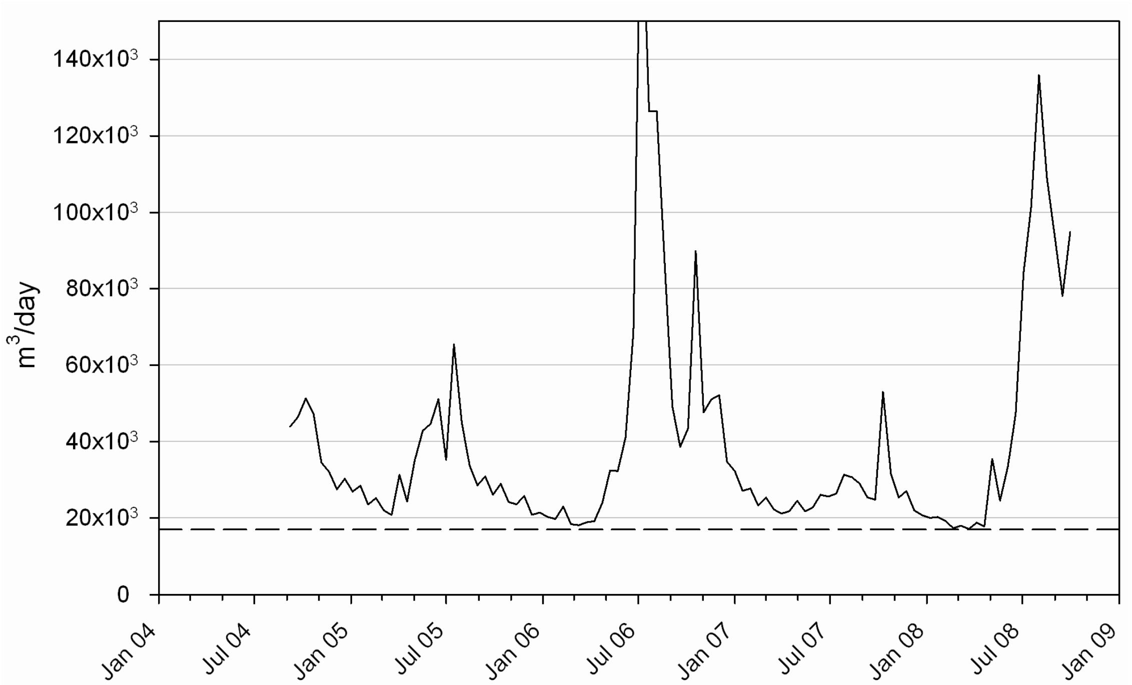

Figure F31: Simulated natural discharge to Featherston springs when there is no groundwater abstraction. Mean low flow is about 17,000 m^3/day (200 L/s) and is indicated by the dashed line.

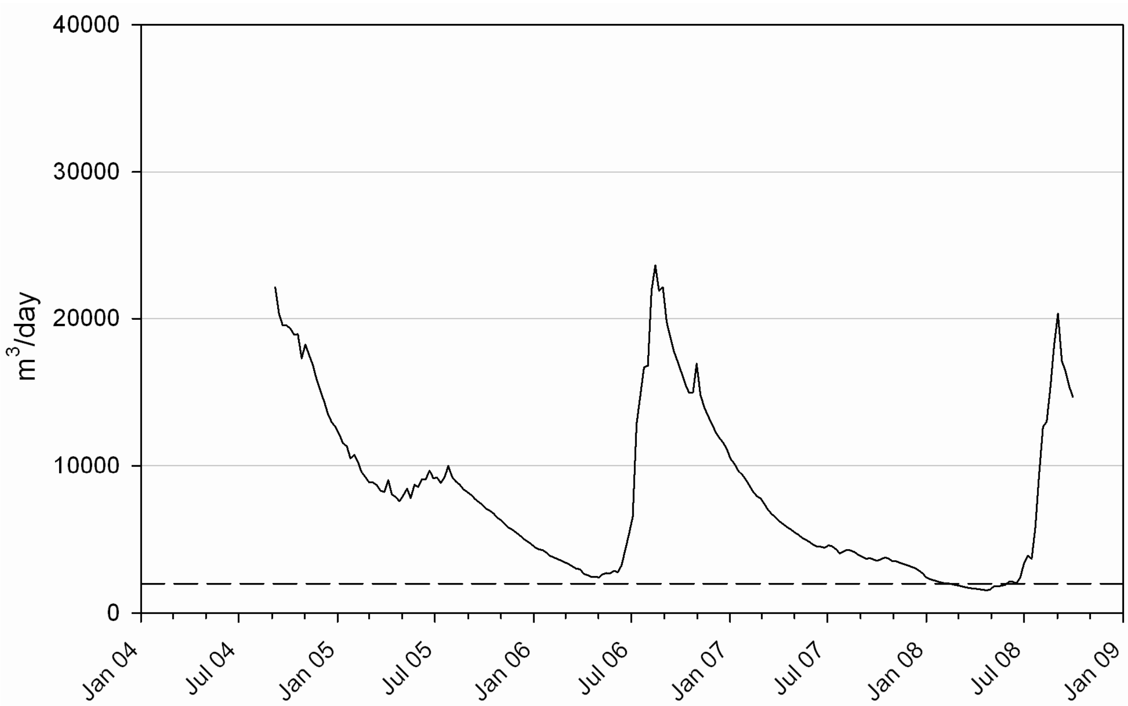

Figure F32: Simulated natural discharge to the Otukura Stream when there is no groundwater abstraction. Mean low flow is about 2,000 m^3/day (23 L/s) and is indicated by the dashed line.

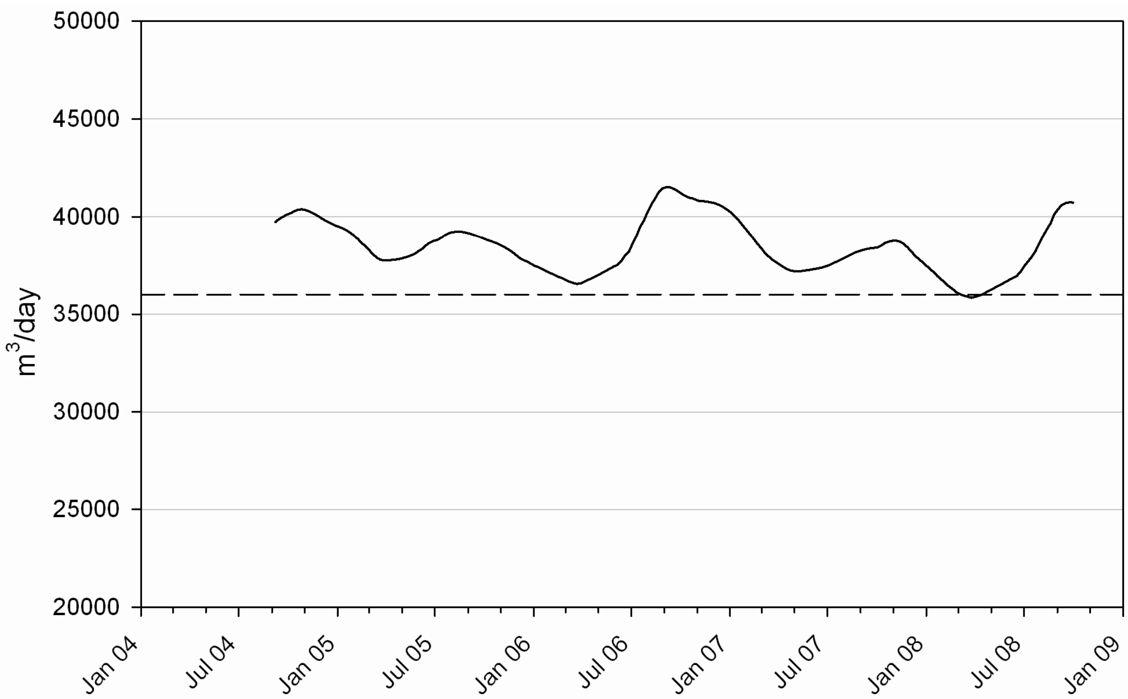

Figure F33: Simulated natural groundwater discharge into Lake Wairarapa when there is no groundwater abstraction. Mean inflow flow is about 37,000 m^3/day (428 L/s) and is indicated by the dashed line.

Table F5: Surface water depletion effects on low flows from groundwater abstraction in the Tauherenikau zone for pumping scenarios 1 to 3. The depletion effects are for the final simulated irrigation season of 2007/08.

	Depletion Scenario 1 Q=32,000[a]	Depletion Scenario 2 Q=25,000	Depletion Scenario 3 Q=22,000	MALF or Mean low flow	q/Q	Scenario 1 Depletion as % of low flow
Tauherenikau River	2,300	1000	800	27,000 (MALF)	0.04	7
Stonestead Creek	9,700	7,000	6,300	65,000	0.28	15
Featherston springs	7,600	5,000	4,700	17,000	0.20	45
Otukura Stream	1,000	800	500	2,000	0.03	50
Lake Wairarapa	6,600 (Fig 4.8)	1,700	1,700	37,000	0.07	18
Total – spring discharge in Tauherenikau zone	18,300	12,800	11,500	85,000	0.5	22

[a] Includes Category A bores

Table F5 also shows the depletion effect on the combined spring discharge in the Tauherenikau zone during low-flow conditions. The total calculated depletion effect of 18,300 m^3/day (excluding the Tauherenikau River) is about 22% of the mean summer spring discharge. On the basis of the model scenarios, this total effect can be attributed to the following abstractions:

- Lake zone abstraction (Table F2): 1,900 m^3/day
- Tauherenikau zone abstraction (Table F6, Scenario 2): 12,800 m^3/day
- Tauherenikau Category A abstraction (balance): 3,600 m^3/day

Table F5 therefore shows the importance of managing the cumulative effects of abstractions from aquifers classified as Category B or C which appear to contribute to more than 70% of the total depletion effect currently occurring in the Tauherenikau water management zone.

F.5.7 Groundwater management options for the Tauherenikau zone

Groundwater-surface water interaction zones

- The Q1 alluvium associated with the Tauherenikau River and the capture zone of the Stonestead Creek (as shown in Figure F17) should be designated Category A to a depth of 20 m.

- Due to the leaky nature of the semi-confined aquifers in this zone and the widespread occurrence of spring discharge on the Tauherenikau fan, the remainder of the zone should be classified as Category B at all depths. This allows the potential nature and magnitude of stream depletion effects to be assessed for individual groundwater takes to identify those bores which have a sufficiently direct hydraulic connection to warrant pumping regulation to mitigate direct effects on surface water.

Groundwater allocation

- Aquifers in the Tauherenikau zone behave as an interconnected (leaky) groundwater system. Model simulations show that the deeper semi-confined aquifers exhibit a significant connection to the surface water environment over relatively short pumping durations. It is therefore recommended that this zone be managed as a single groundwater resource.

- There are numerous spring-fed groundwater dependent ecosystems in this zone which are highly sensitive to groundwater abstraction. The cumulative effects of unregulated groundwater abstraction should be referenced to an acceptable effect on the total spring discharge from the Tauherenikau zone. The Tauherenikau River appears to be relatively insensitive to the cumulative effects of abstraction outside Category A and it is therefore not recommended that this river be used as a reference for allocation.

- Adoption of a combined baseflow coefficient[34] for zonal spring discharge of 0.5 will reflect the response of the groundwater system to abstraction (see Table F5).

- Abstraction from the adjacent Lake zone will result in an additional depletion effect in the Tauherenikau zone. Modelling of the Lake zone suggests that this will be about 8% of the Lake zone abstraction rate (q/Q = 0.08). This additional effect should be taken into consideration when determining allocation volumes for the Tauherenikau zone.

- The Tauherenikau zone abstraction will result in a depletion effect on Lake Wairarapa. This additional effect should be taken into consideration when determining allocation volumes for the Lake zone.

Table F6 outlines potential allocation options for the Tauherenikau water management zone, taking into account the interference effect from the down-gradient Lake zone.

Option 1 is recommended since groundwater modelling in this zone indicates that springs and streams are particularly sensitive to groundwater abstraction. Furthermore,

[34] Baseflow coefficient = fraction of pumping rate which contributes to surface water depletion. Obtained from model scenarios.

abstraction from this zone also impacts on groundwater and surface water discharge to Lake Wairarapa.

The current total consented groundwater allocation from the Tauherenikau water management zone – including Category A (as defined in Figure F17) – is 56,900 m^3/day from 38 bores. Excluding those shallow bores in the area classified as Category A (direct hydraulic connection), the total consented abstraction from this zone is 48,200 m^3/day. The metered actual usage during the 2007/08 irrigation season was about 60% of the consented abstraction. Since groundwater level monitoring data indicate declining groundwater levels and large seasonal drawdowns in the semi-confined aquifer (refer to Gyopari and McAlister 2010c), it is therefore appropriate to adopt Option 1. Under Option 1, the depletion of Lake Wairarapa would be approximately 2,500 m^3/day (0.07 x 36,000 – see Table F5), and the depletion of the Tauherenikau River would be 1,440 m^3/day (0.04 x 36,000), or 8% of MALF. Depletion of the various springs in this zone can also be calculated using the information in Table F5.

Table F6: Allocation options for the Tauherenikau water management zone based upon the total spring depletion and a q/Q ratio of 0.5. Total spring discharge assumed to be 85,000 m^3/day (summer mean; see Table F5). Contribution to depletion from Lake zone abstraction rate is based on q/Q = 0.08 and Q = 37,500 m^3/day. Annual allocation is based on pumping at the maximum daily rate for 180 days. The percentage of LSR (land surface recharge) is for reference and is based on a calculated lower quartile annual recharge of 26.4 x $10^6 m^3$.

Options	A Depletion effect –% of mean summer spring discharge	B Total depletion allowed (m^3/day)	C Lake zone depletion contribution (m^3/day)	D Depletion Allowance balance (m^3/day)	E Daily allocation if q/Q = 0.5 (m^3/day)	F Annual allocation (m^3 x 10^6/year)	G % lower quartile annual LSR
1	25%	21,250	3,000	18,250	36,500	6.57	25
2	35%	29,750	3,000	26,750	53,500	9.63	36
3	:50%	42,500	3,000	39,500	79,000	14.2	54

Table explanation:

A: percent depletion of total spring discharge in Tauherenikau Zone (85,000m^3/day; Table F5)
B: A * 85,000
C: Cross-zone interference depletion effects from pumping in the Lake Zone (0.08 * 37,500)
D: B – C
E: D / 0.5
F: Annual allocation as a percentage of the lower quartile annual rainfall recharge over the zone (=26.46x$10^6 m^3$)

F.6 Moiki water management zone

F.6.1 Overview

Delineation: The Moiki water management zone is a 9 km reach of the Ruamahanga valley between the northern edge of the Lower Valley catchment and the Huangarua confluence. The zone is about 2 km wide and has a relatively shallow fill of Q1 and Q2 alluvium (Figure F34).

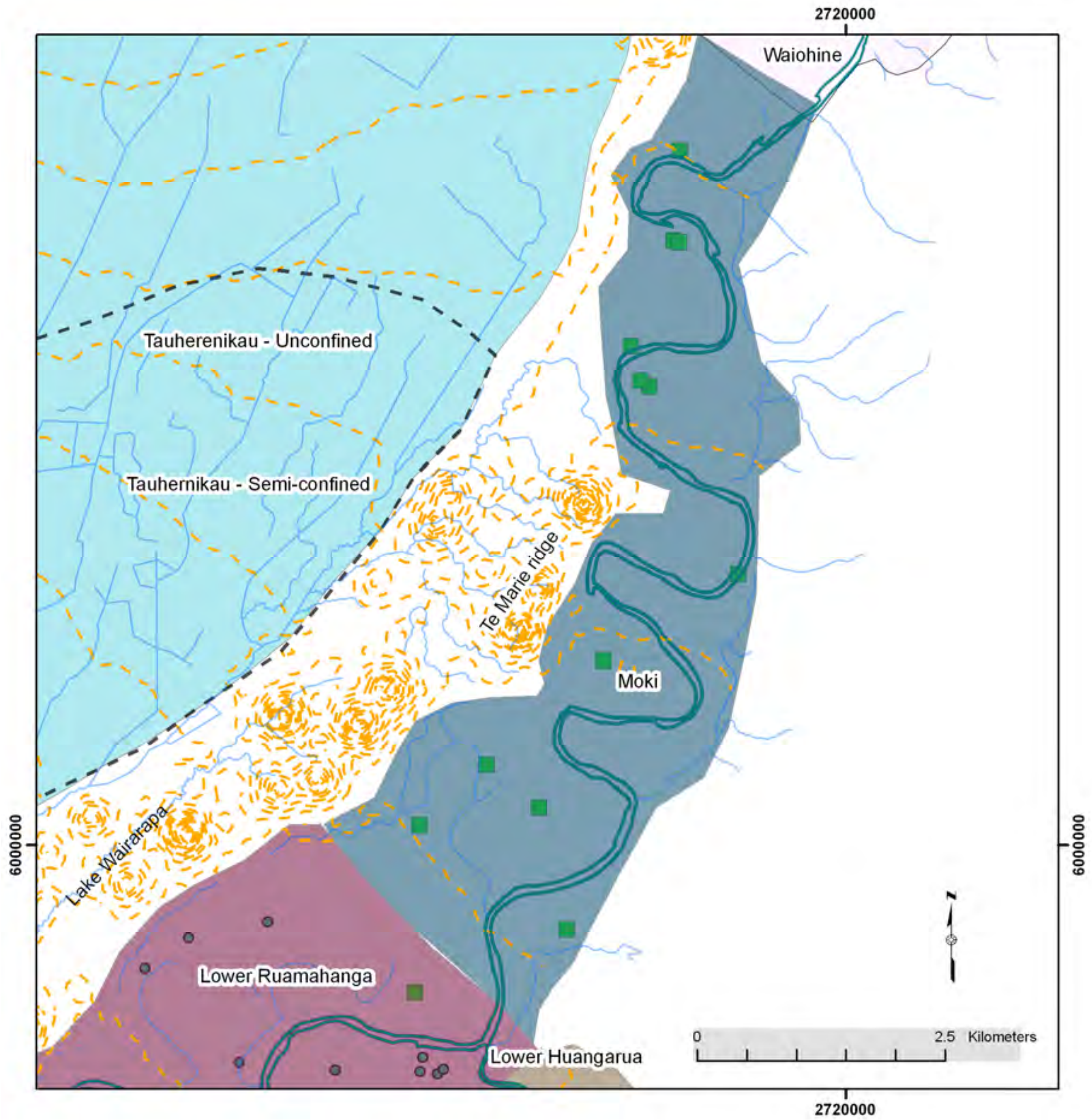

Figure F34: The Moiki water management zone defined by the recent alluvium of the Ruamahanga River valley on the eastern side of Te Maire ridge. The map shows existing groundwater bores with consented abstraction (green squares and circles) and groundwater flow contours (brown dashed lines).

Area:	18 km^2.
Boundaries:	The western boundary is coincident with the base of Te Maire ridge, an uplifted block of basement and older Quaternary sediments. The eastern boundary follows the contact between late Quaternary valley-fill alluvium and the early-mid Quaternary or Tertiary eastern hills sequences. The southern zone boundary extends across the valley at the Huangarua River confluence and marks the point at which the base of the aquifer sequence starts to deepen down-valley. The northern edge represents the upstream boundary of the Lower Valley catchment at the northern end of Te Maire ridge.
Principal surface water system:	Ruamahanga River.
Aquifer sequences:	Shallow unconfined aquifer to 10 to 15 m depth
Recharge:	Estimated average annual rainfall recharge is 1.6 x 10^6 m^3 (4,380 m^3/day)
Existing RFP zones:	Middle Ruamahanga (shallow and deep aquifers).
Existing allocation:	Table F7 shows the existing allocation status of the Moiki water management zone.

Table F7: 'Safe yield' estimates and current groundwater allocation status (as at June 2010) for existing RFP (WRC 1999) groundwater zones within the Moiki water management zone

Existing RFP zone	RFP 'safe yield' (m^3/year)	Current allocation (m^3/day)	Current allocation (m^3/year)	% allocated
Riverside 10 consents (13 bores)	3.9 x10^6	24,285	3.9 x10^6	100

F.6.2 Hydrogeology summary

The Moiki zone is an unconfined to semi-confined aquifer system comprising permeable (Q1+Q2) gravels. Overall, the aquifer system is typically 15 to 20 m thick but deepens to about 30 m toward the southern zone boundary. Groundwater recharge occurs via rainfall infiltration and river losses. The primary groundwater discharge process in this zone occurs via local abstraction and throughflow to the Lower Ruamahanga zone.

F.6.3 Hydrology

The Moiki zone is defined by the recent alluvium (Q1 and Q2) of the Ruamahanga River valley. Flows in the lower Ruamahanga River are monitored at Waihenga bridge (just below the Huangarua River confluence) where the calculated MALF (7-day) is reported to be 8.77 m^3/s. Further upstream, the instream flow assessment study for the Lower Ruamahanga River reported the naturalised MALF to be 10.7 m^3/s along the Morrisons Bush reach (Cawthron 2008).

Within the Moiki zone, the Ruamahanga River generally loses flow to groundwater. A concurrent gauging run in February 2006 showed a flow loss of about 2,000 m^3/day (228 L/s) between Morrisons Bush and Moiki (notwithstanding the potential magnitude of gauging error). Groundwater flow modelling (Figure F35) predicts a mean flow loss of 25,000 m^3/day (290 L/s) and an average summer-early winter loss (when groundwater levels are lowest) of 35,000 m^3/day (405 L/s).

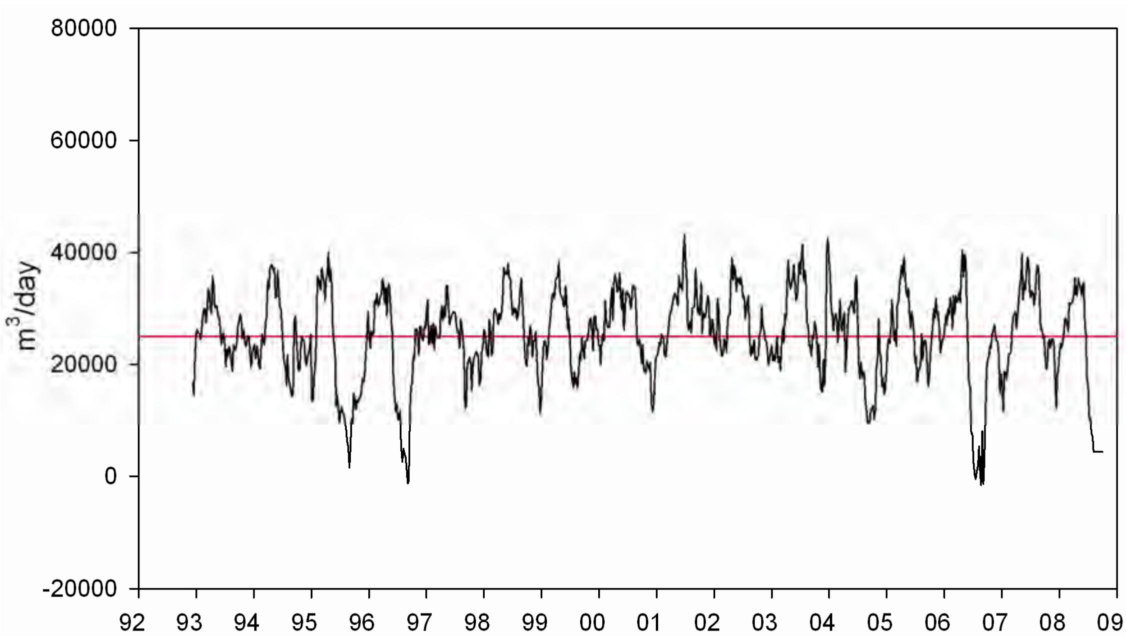

Figure F35: Simulated net flow loss from the Ruamahanga River to adjacent aquifers in the Moiki zone when there is no groundwater abstraction. Losses are greater during summer and early winter when groundwater levels are lowest and therefore the vertical hydraulic gradient beneath the river bed is highest. The significantly lower flow losses modelled during 2006 reflect a high rainfall recharge year when groundwater levels remained high.

F.6.4 Zone management objective

The principal management objective for groundwater allocation in the Moiki zone is to ensure the sustainable use of groundwater resources while protecting the instream values of hydraulically connected surface water ecosystems.

Within the Moiki zone, only the Ruamahanga River has a direct connection to the groundwater environment and the protection of baseflow in this river is therefore of primary importance.

F.6.5 Numerical modelling

The numerical groundwater flow model for the Lower Valley catchment was used to assess the sustainability of current groundwater abstractions and to develop sustainable allocation options for the Moiki water management zone. Details of the model and its calibration are provided by Gyopari and McAlister (2010c).

Baseline (no-abstraction) water balance

The groundwater model was used to quantify the natural water balance for the Moiki zone by running the model for a period of 16 years (1992 to 2008) in the absence of abstraction. This scenario provides a baseline simulation against which the effects of abstraction can be evaluated. Of particular relevance to assessing the sustainability of abstraction, the model provides information on the cumulative depletion effects of groundwater pumping on the Ruamahanga surface water environment.

The principal water balance components for the Moiki zone are rainfall recharge, groundwater loss from the Ruamahanga River, abstraction and throughflow to the downstream Lower Ruamahanga zone.

Figure F36 shows the modelled annual rainfall recharge for the Moiki zone for the period 1992 to 2008. The average annual rainfall recharge for this period is 1.6×10^6 m^3 (equivalent to a long term mean of 4,400 m^3/day).

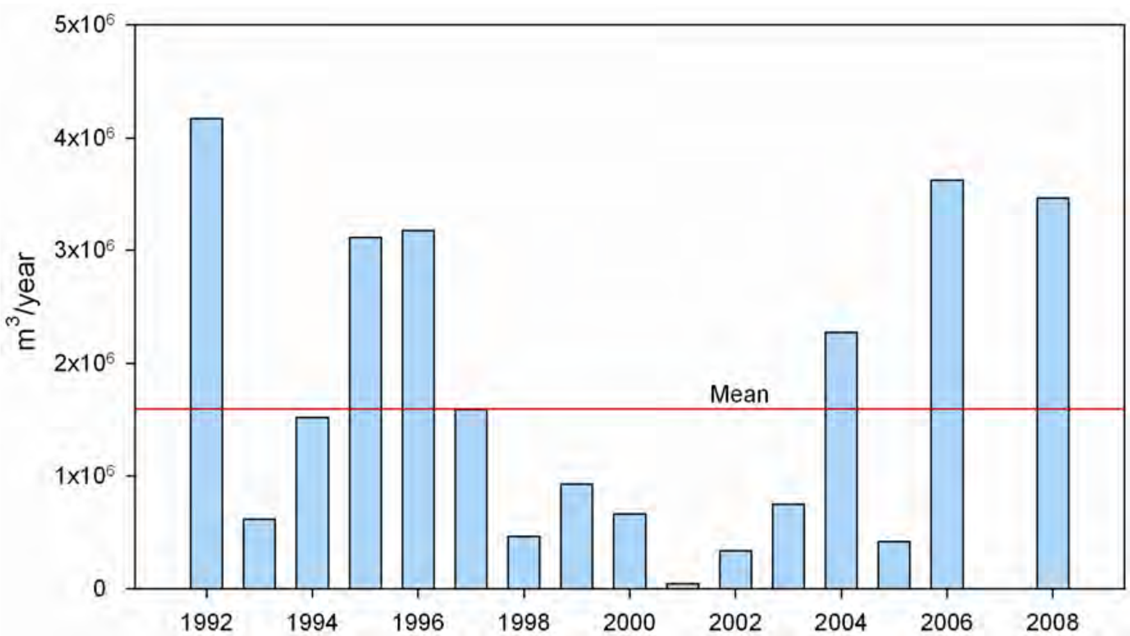

Figure F36: Modelled annual rainfall recharge for the Moiki zone (mean annual recharge of 1.6×10^6 m^3/year)

Abstraction from the Moiki zone was simulated for the 16-year transient model run and is shown in Figure F37. Seasonal abstraction only commenced in 2002/03 and now peaks at approximately 10,500 m^3/day (estimated actual abstraction using the methodology described in Gyopari and McAlister 2010c). The current consented abstraction is 22,000 m^3/day and therefore estimated use is about half the total consented daily rate.

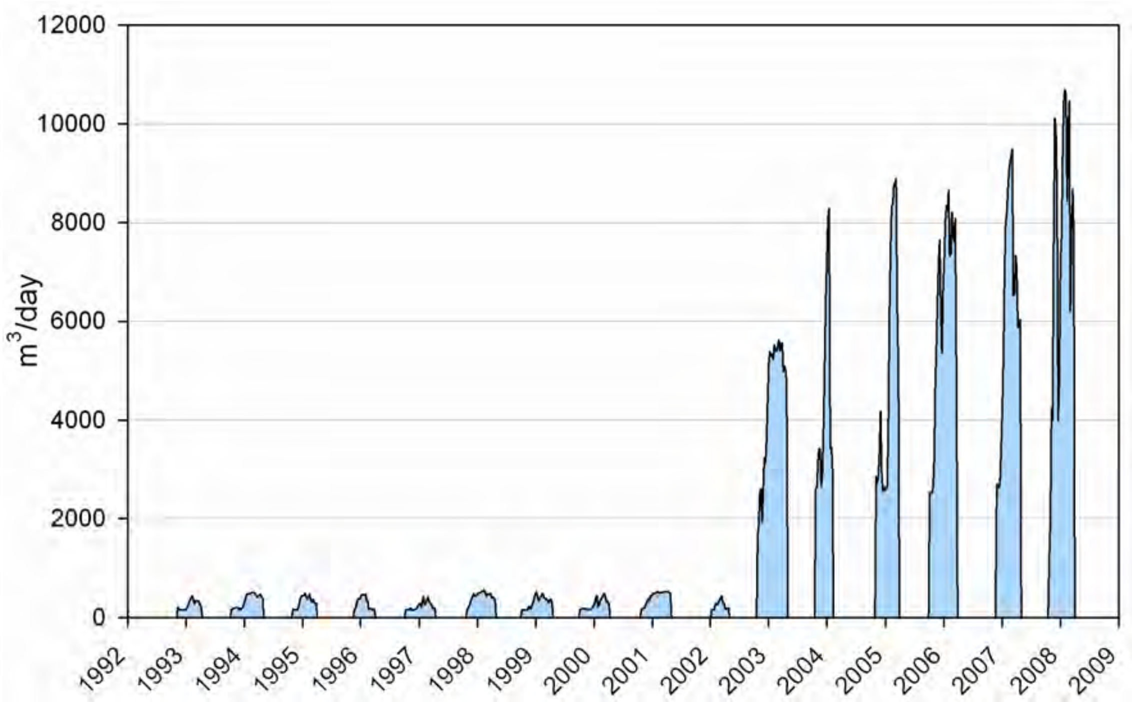

Figure F37: Simulated historic abstraction in the Moiki zone from 11 bores. Large-scale irrigation abstraction only commenced in the 2002/03 summer. The estimated 2007/08 peak abstraction rate is equivalent to the Middle Ruamahanga zone in the Middle Valley catchment. Consented allocation from the Moiki zone is about 22,000 m^3/day and therefore actual use is estimated to be approximately 50% of the consented rate.

The numerical model was used to simulate the potential stream depletion effect of the abstraction pattern shown in Figure F37 on the Ruamahanga River. Figure F38 shows the simulated increase in flow loss from the Ruamahanga River resulting from historical abstraction derived by comparing the baseline non-pumping simulation with the historical abstraction simulation. The model predicts that total seasonal depletion is in excess of 90% of the cumulative zonal abstraction rate thereby indicating a direct connection between the aquifer and the river in this zone. The plot shows that during winter periods and pre-2003 (when large-scale abstraction commenced) the depletion rate exceeds the pumping rate. This is because bores in the adjacent Lower Ruamahanga zone (including public water supply bores for Martinborough) are also pumping and cause additional depletion effects in the Moiki zone. It is also important to note that when pumping ceases at the end of an irrigation season, the depletion rate drops rapidly. This illustrates the potential for regulation of these takes with respect to river flows as an option for mitigating the impacts of groundwater abstraction on low flows in the Ruamahanga River.

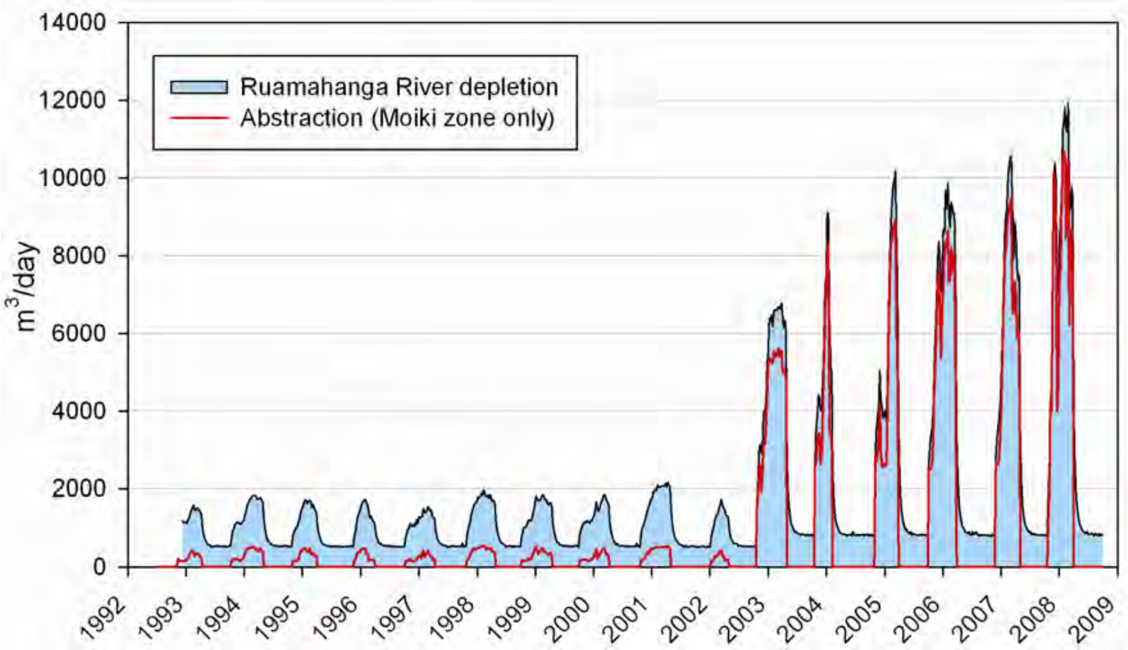

Figure F38: Simulated flow loss (or depletion) from the Ruamahanga River in the Moiki zone resulting from historic abstraction. It is clear that abstraction from the adjacent Lower Ruamahanga zone results in additional depletion effects so that total depletion in the Moiki zone exceeds the Moiki zone abstraction rate at times.

F6.6 Groundwater management options for the Moiki water management zone

Groundwater-surface water interaction zones

- Due to the very high degree of connectivity between the unconfined aquifer and the surface water environment, the entire Moiki zone should be classified as Category A (direct hydraulic connection).

Groundwater allocation

- No groundwater allocation is required in this zone since all takes will be managed as equivalent surface water takes under the Category A criteria.

F.7 Martinborough water management zone

F.7.1 Overview

Delineation: The Martinborough water management zone is a geologically and hydrogeologically distinct area of elevated older alluvial terrace sequences located between the Ruamahanga River and Harris anticline (Figure F39). Groundwater in this zone discharges north-westwards into the Lower Ruamahanga zone.

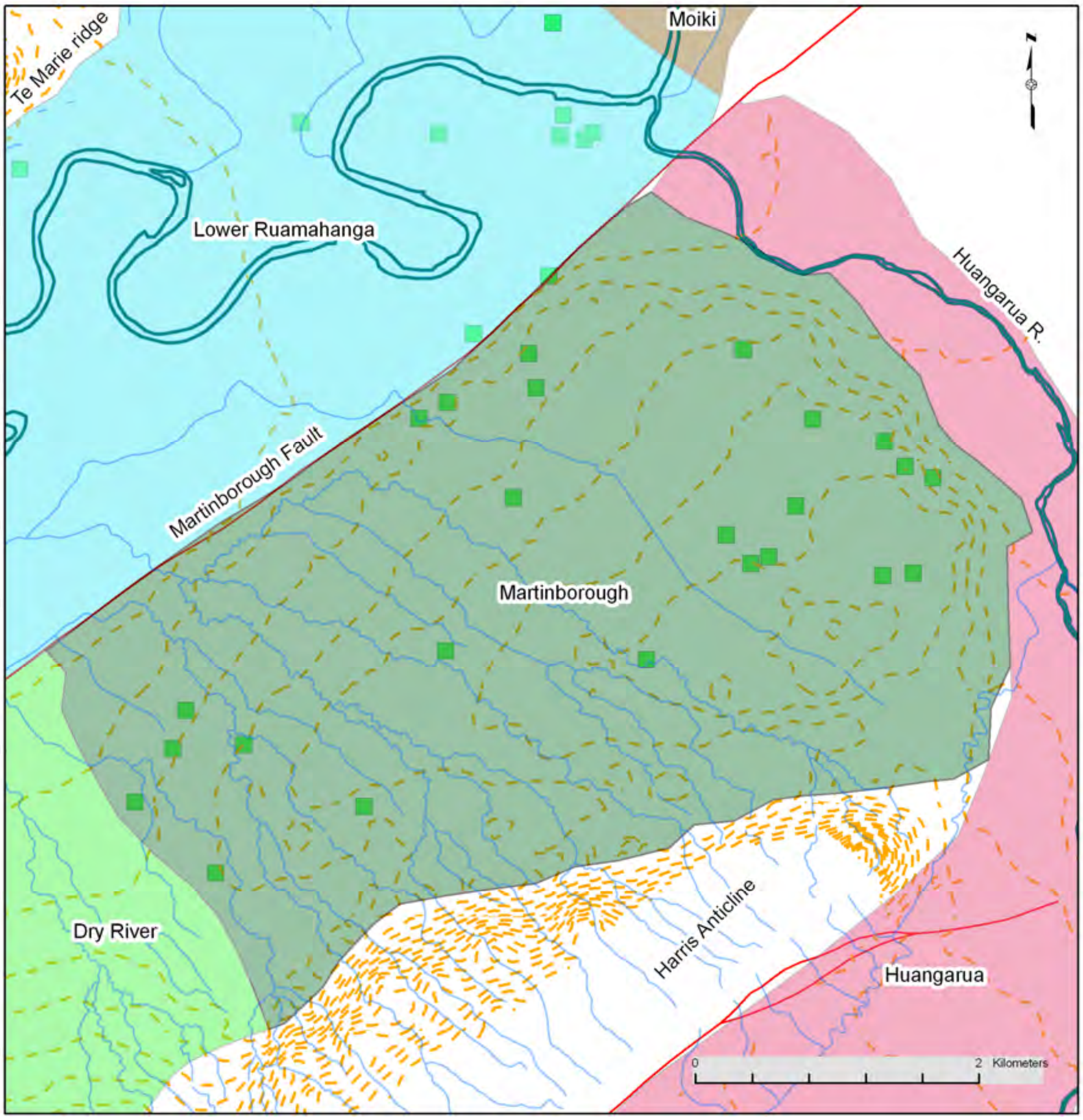

Figure F39: The Martinborough water management zone map showing existing groundwater bores with consented abstraction (green squares), groundwater flow contours (brown dashed lines) and neighbouring zones

Area:	22.4 km^2
Boundaries:	The western boundary is aligned with the Martinborough Fault which offsets the geological sequence but does not constitute a barrier to groundwater flow in the shallower aquifers. The eastern zone boundary follows the edge of late the Quaternary sequence where they onlap onto the Tertiary sediments which outcrop along the axis of the Harris anticline. The northern zone boundary is coincident with the edge of the Martinborough terraces above the Huangarua valley. The southern boundary marks a transition to a sequence of younger alluvial deposits.
Principal surface water systems:	None.
Aquifer sequences:	Upper semi-confined 20 to 30 m deep (Q4/6) Deep confined aquifer > 60 m (mQa)
Recharge:	Estimated average annual rainfall recharge 2.15 x 10^6 m^3/year (approximately 5,900 m^3/day)
Existing RFP zones:	Martinborough eastern terraces, Martinborough western terraces (see Table F8)

Table F8: 'Safe yield' estimates and current groundwater allocation status (as at June 2010) for existing RFP (WRC 1999) groundwater zones within the Martinborough water management zone

Existing RFP zone	RFP 'safe yeld' (m^3/year x 10^6)	Current allocation (m^3/day)	% allocated
Martinborough eastern terraces (entire)	0.31	2,060	135
Martinborough western terraces (part)	1.5	7,300	84
Total	1.81	9,300	

F.7.2 Hydrogeology summary

The Martinborough zone occupies the area of uplifted alluvial terraces associated with the Harris anticline. The terrace deposits consist mainly of alluvial gravel and sand with minor silt and swamp deposits. Most of the gravel deposits are clay-bound and exhibit low hydraulic conductivities. Groundwater abstraction commenced in this zone in the early 1990s for vineyard irrigation. A semi-confined sand and gravel aquifer is identified dipping to the west off the Harris anticline which is underlain by a deeper, low permeability confined aquifer. The upper, more productive aquifer (in which most bores are screened) occurs between 15 and 35 m depth and sustains individual bore yields of between 1 and 15 L/s. The alluvium comprising this aquifer is interpreted to be of late Quaternary age (Q4 or Q6 age) and is inferred to be in hydraulic continuity with the Ruamahanga valley alluvium suggesting throughflow occurs across the Martinborough Fault into the Lower Ruamahanga zone.

Deeper bores intercept older, less permeable terrace alluvium which is interpreted to be of mid Quaternary age (mQa) outcropping to the east on the Harris ridge (refer to Hydrostratigraphic Unit E in Tables 6.1 and 6.2 of Gyopari and McAlister (2010c) for further details). This deeper ‘mQa aquifer sequence’ is confined by a thick aquitard of possible interglacial Ahiaruhe age and has a groundwater head some 10 m higher than overlying aquifers. The maximum depth of the deep aquifer has been estimated to be about 70 to 80 m on the downthrown eastern side of the Martinborough Fault thinning towards the anticline axis to the east. This aquifer is isolated from the down-valley groundwater environment by displacement along the Martinborough Fault and has relatively poor groundwater potential (although individual well yields are sufficient to enable low-demand irrigation).

The Martinborough terraces are recharged solely from rainfall infiltration, both on the terraces and the adjacent Harris anticline.

F.7.3 Hydrology

There are no significant rivers or streams in the Martinborough zone aside from numerous ephemeral channels which drain the Harris anticline during wet periods (see Figure F39).

F.7.4 Zone management objectives

There are no surface water systems in this zone aside from ephemeral runoff streams. The principal objective of groundwater allocation in the Martinborough zone is therefore to ensure the sustainable use of groundwater resources by having specific regard to:

- Rainfall recharge
- Interference effects on existing groundwater users

Interference effects on existing groundwater users will be addressed by specific policy rules. Therefore, the allocation volume for this zone should be based upon a proportion of calculated rainfall recharge.

F.7.5 Numerical modelling

The calibrated numerical groundwater flow model for the Lower Valley catchment has been used to assess the sustainability of current groundwater abstractions and to develop sustainable allocation options for the Martinborough water management zone. Details of the model and its calibration are provided by Gyopari and McAlister (2010c).

Zone water balance

The groundwater model was used to quantify the natural water balance for the Martinborough zone by running the model for a period of 16 years (1992 to 2008) with no abstraction occurring. The principal water balance components of the zone are: rainfall recharge, throughflow to the Lower Ruamahanga zone and groundwater abstraction.

Figure F40 shows the modelled annual rainfall recharge for the period 1992 to 2008 derived from soil moisture balance modelling. The average annual recharge for the zone is calculated to be 2.15 x 10^6 m^3. It is noted that this recharge estimate is considerably lower than results from a previous analysis (Butcher 2001[35]) which estimated the annual recharge on the Martinborough terraces to be 9.1 x 10^6 m^3/year (for a slightly larger area than the Martinborough zone). For details on climate and recharge modelling methodology refer to Gyopari and McAlister (2010c).

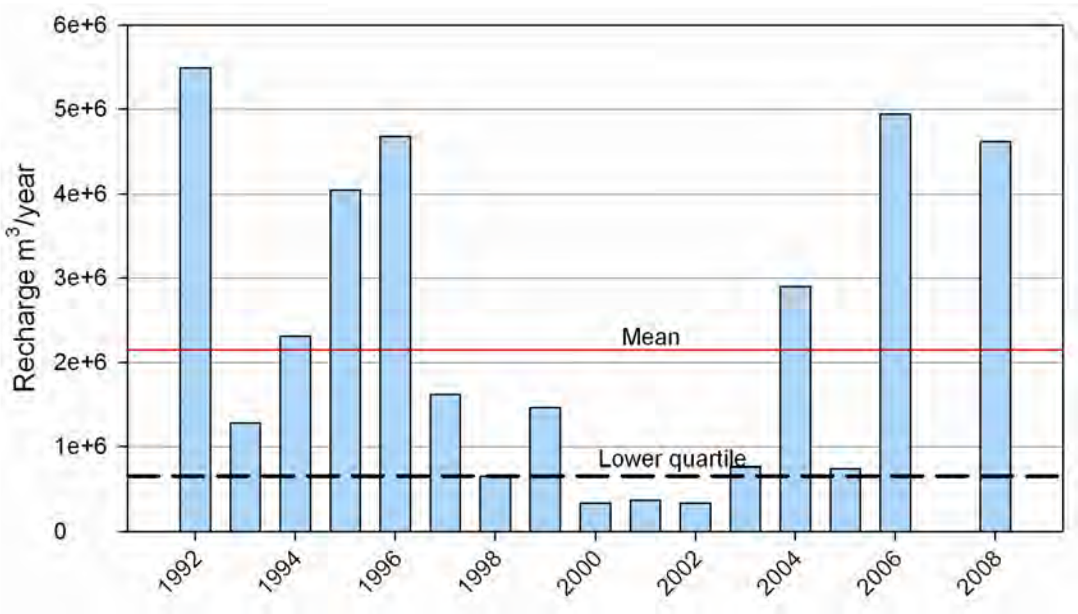

Figure F40: Modelled annual rainfall recharge for the Martinborough zone (mean annual recharge is 2.15 x 10^6 m^3 and the annual lower quartile recharge is 0.66 x 10^6 m^3 for the period 1992 to 2008)

The simulated throughflow from the Martinborough zone into the Lower Ruamahanga zone across the Martinborough Fault is shown in Figure F41. The throughflow trend is strongly influenced by the temporal variations in rainfall recharge with the effects of the low-rainfall period between 1997 and 2003 being reflected in reductions in throughflow during this period. The mean throughflow of 8,800 m^3/day is comparable in magnitude to the mean daily rainfall recharge of about 6,000 m^3/day.

[35] Butcher, G. 2001. *The groundwater resources of the Martinborough terraces groundwater zone*. Internal report, WRC.

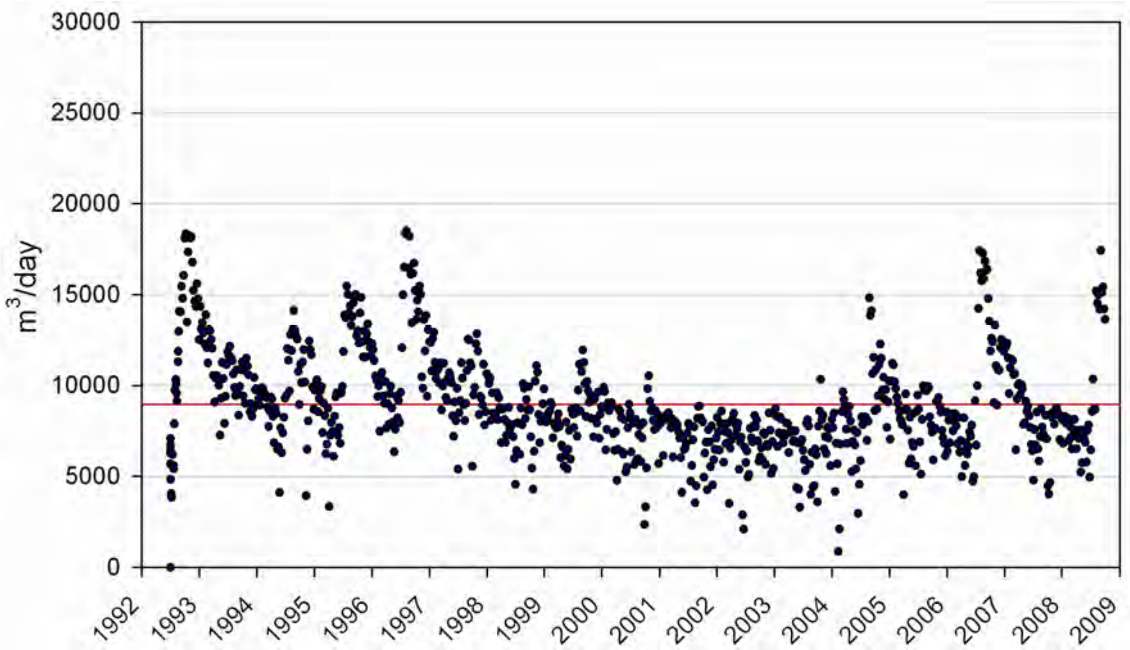

Figure F41: Simulated throughflow westwards from the Martinborough zone into the Ruamahanga Valley for the period 1992 to 2008. The long-term trend reflects climate and recharge variability. The mean throughflow for this period is about 8,800 m^3/day (100 L/s).

As at June 2010, there were 24 bores in the Martinborough zone with a total consented abstraction rate of 5,800 m^3/day. All but two of these bores abstract from the upper (Q4–Q6) semi-confined aquifer sequence. The actual abstraction rate has been estimated using annual meter data and estimated irrigation season length. Figure F42 shows the modelled abstraction trend between 1992 and 2008, peaking at about 2,100 m^3/day which represents approximately 35% of the consented daily abstraction rate. Since daily records are not available, the estimated daily use is probably underestimated as metering data collected elsewhere in the Wairarapa Valley suggests that the mean actual daily use is often 60 to 70% of the consented rate. However, annual meter records in the Martinborough water management zone indicate that total annual use is less than 30% of the consented volume.

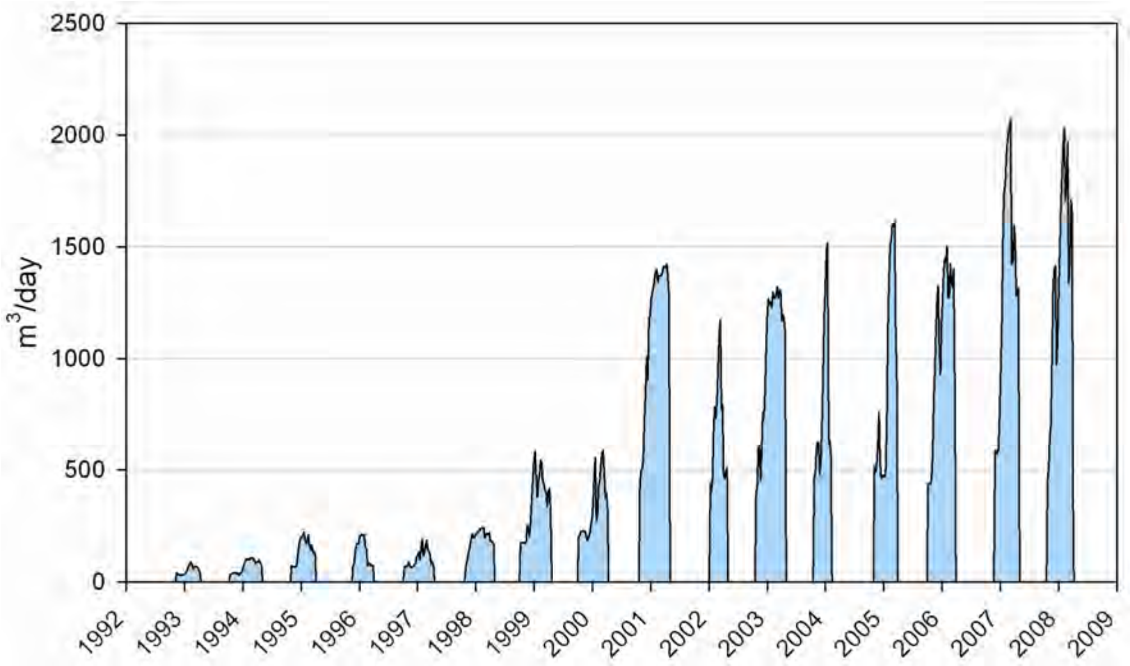

Figure F42: Simulated groundwater abstraction trend in the Martinborough zone between 1992 and 2008 based on annual meter data and estimated irrigation season duration

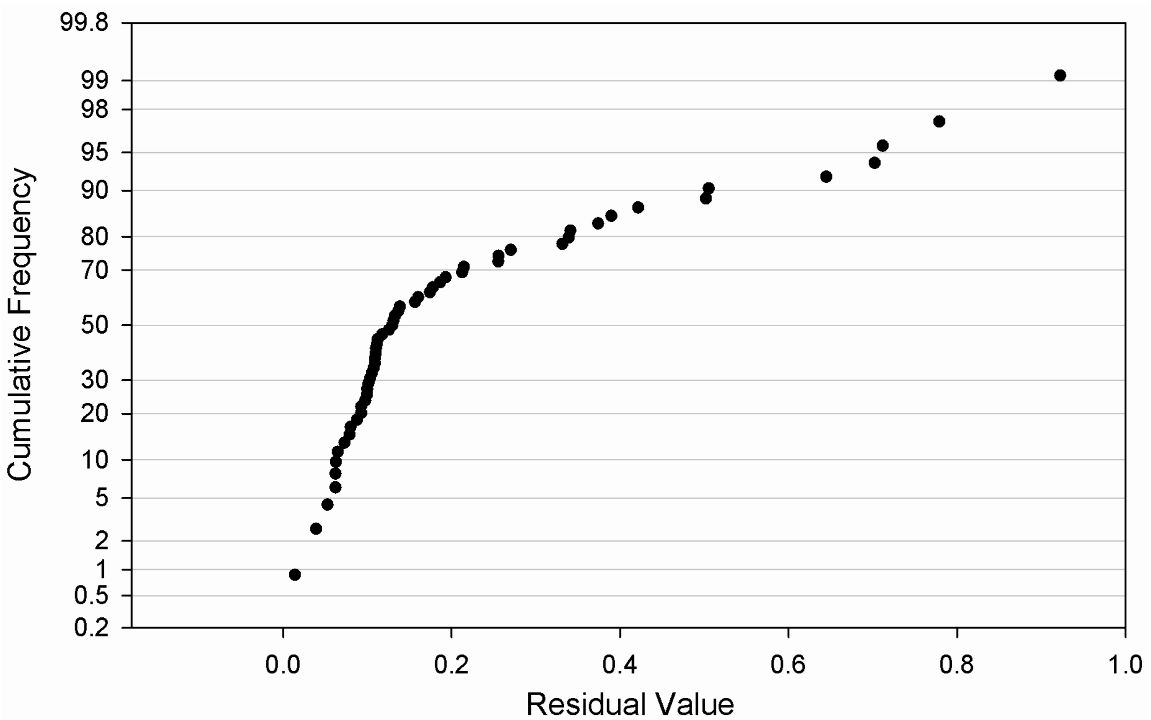

Figure F43: Cumulative frequency plot for annual meter reading data expressed as a fraction of the consented annual abstraction rate. Data from 2002 to 2008 for 12 bores in the Martinborough zone

Pumping effects

The principal effect of groundwater abstraction from the Martinborough zone is the reduction in throughflow to the adjacent down-gradient Lower Ruamahanga zone. Figure F44 shows the simulated depletion of throughflow across the Martinborough Fault. The modelled reduction in throughflow is approximately 50% of the cumulative pumping rate from the Martinborough zone. Because bores in the Lower Ruamahanga zone also cause a small enhancement in throughflow across the fault (including the Martinborough public supply bores which pump year-round), the plot shows a small negative depletion when there is no pumping from the Martinborough zone (and prior to 2001 when there was limited irrigation abstraction).

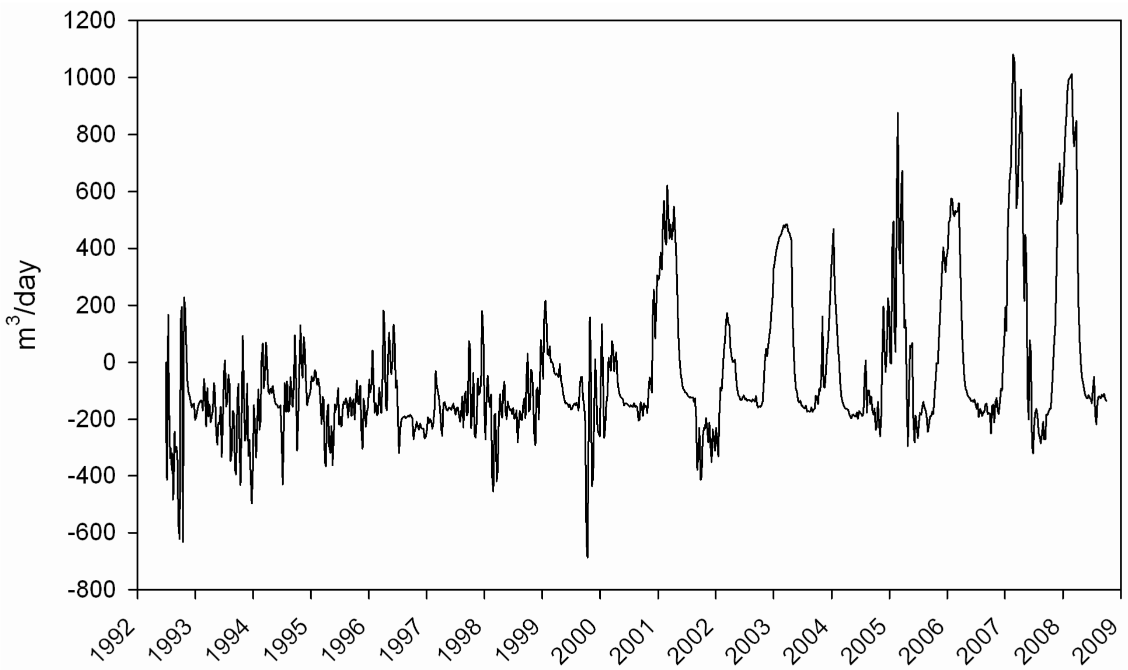

Figure F44: Simulated reduction in throughflow from the Martinborough zone across the Martinborough Fault to the Lower Ruamahanga zone. The depletion reflects the abstraction trend in Figure F42 and attains about 50% of the abstraction rate. Apparent negative depletions are due to pumping effects in the adjacent Lower Ruamahanga zone, including public water supply bores which induce small increases in throughflow from the Martinborough zone.

F.7.6 Groundwater management options for the Martinborough water management zone

Groundwater-surface water interaction zones

- Since there are no surface water systems which will be affected by abstraction it is recommended the entire Martinborough water management zone is classified as Category C (moderate hydraulic connection) and managed in terms of total groundwater allocation.

Groundwater allocation

- The aquifers in the Martinborough zone should be managed as a single resource. A majority of existing abstraction occurs from the Q4/6 semi-confined more productive system.

- This zone is recharged solely from rainfall infiltration and there are no hydraulically connected surface water ecosystems. Minor effects on the Ruamahanga zone will occur through the reduction in throughflow across the Martinborough Fault. Allocation should therefore be referenced to the lower quartile annual recharge since this offers a more realistic annual figure given the observed very high variability in rainfall recharge (Figure F40) . This is estimated to be in the order of 0.66 x 10^6 m^3/year for the period 1992 to 2008 which is about 33% of the mean annual recharge. This period incorporates a wide range of climatic conditions (see Gyopari and McAlister 2010c, Section 11.4).

- The annual recharge rate has a high standard deviation (see Figure F40). For the 1992 to 2008 period, the lower quartile recharge quantity was about 0.7 x 10^6 m^3/year, or about 33% of the mean recharge. The annual allocation limit should not exceed 30 to 40% of the mean annual recharge rate to allow for successive years low rainfall recharge.

- Allocation should be expressed in terms of both annual maximum and a weekly maximum. The weekly maximum should be based upon a 180 day irrigation season.

Table F9 outlines allocation options for the Martinborough water management zone based on a proportion of rainfall recharge. Since potential depletion effects on surface water ecosystems is not an issue in this zone, groundwater can safely exceed 100% of the lower quartile rainfall recharge. However, to avoid long term aquifer drawdowns it is recommended that allocation remains below about 30-50% of the annual average recharge. Option 4 is therefore recommended.

Table F9: Suggested allocation options for the Martinborough water management zone based on a proportion of estimated annual rainfall recharge

Options	Allocation reference % of LQLSR*	Allocation (m^3/year x 10^{6})	Allocation (m^3/day)
1	70	0.46	2,600
2	90	0.59	3,300
3	100	0.66	3,650
4	120% (37% mean annual LSR)	0.79	4,400
5	150 (46% mean annual LSR)	0.99	5,500

*LQSR = lower quartile land surface recharge (rainfall recharge).

Current daily allocation from the 24 bores located in the Martinborough zone as delineated in Figure F17 is about 5,800 m^3/day (40,600 m^3/week). However, actual daily use is likely to be significantly less than 70% of the total consented rate and is therefore predicted to be 4,000 m^3/day or less (28,000 m^3/week).

F.8 Lower Ruamahanga water management zone

F.8.1 Overview

Delineation: The Lower Ruamahanga water management zone incorporates an 11 km section of the Ruamahanga valley between the Huangarua River confluence and the end of Te Maire ridge (Figure F45). The zone is about 3 km wide and contains a southerly-deepening late Quaternary unconfined-semi-confined aquifer sequence.

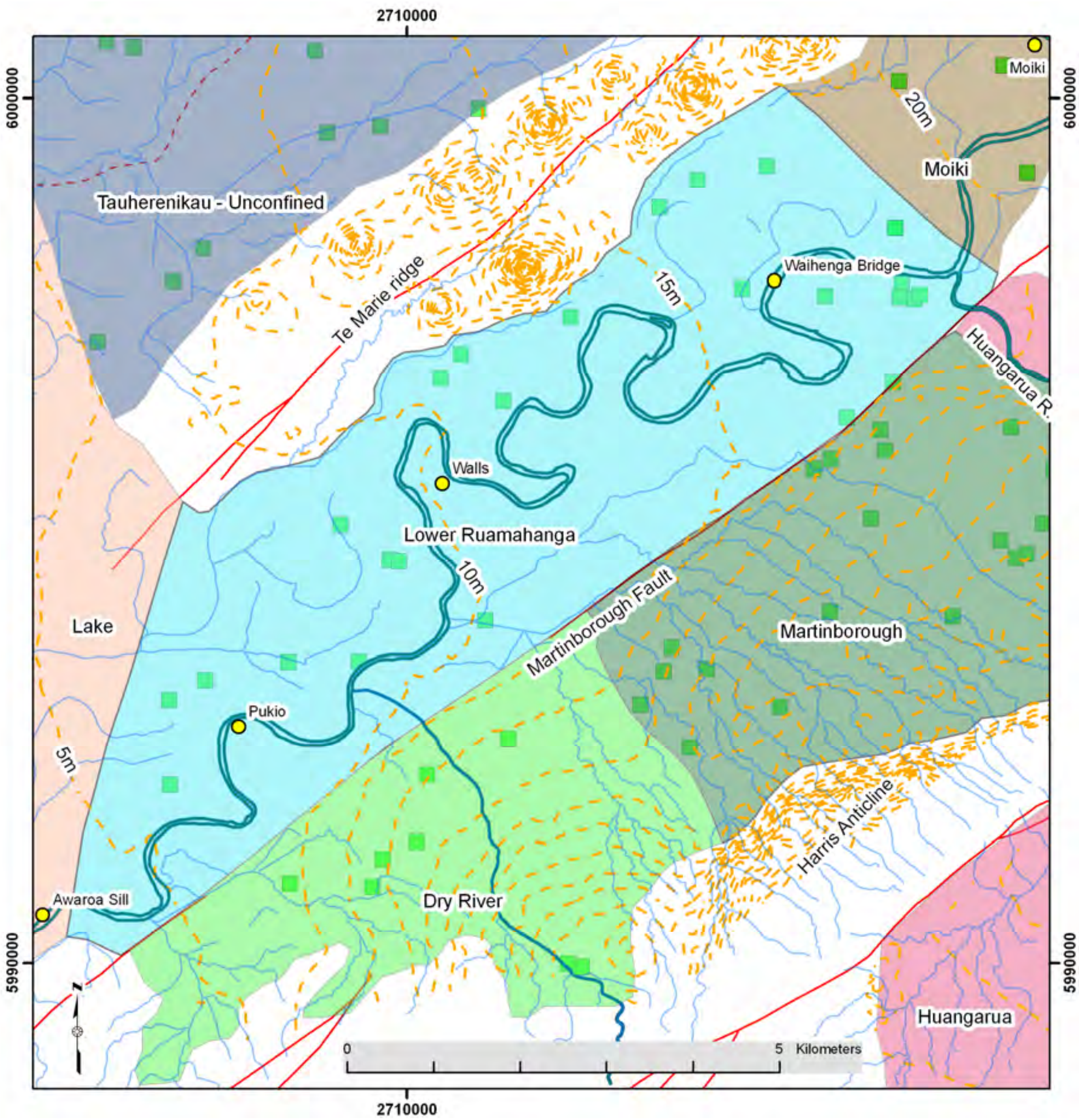

Figure F45: The Lower Ruamahanga water management zone defined by the recent (Q1) alluvium of the Ruamahanga River valley between Te Maire ridge and the Martinborough Fault. The map shows existing groundwater bores with consented abstraction (green squares) and groundwater flow contours (brown dashed lines at 5 m intervals – m amsl). Concurrent gauging sites on the Ruamahanga River also shown (yellow circles)

Area: 39 km^2.

Boundaries: The north-western boundary is coincident with the base of Te Maire ridge – an uplifted block of basement and older Quaternary sediments.

The south-eastern zone boundary follows the Martinborough Fault. The fault separates older Quaternary sequences of the Martinborough zone from the younger, more permeable Ruamahanga valley sequence. It does not, however, form an impermeable boundary with throughflow occurring across the fault from the Martinborough and Dry River zones.

The northern upstream edge of the zone borders the Moiki zone and represents the general location where the aquifer sequence appreciably thins to the north. The southern boundary marks the contact with the Lake zone south of which the aquifers become confined beneath lake sediments. The hydraulic gradient in the groundwater system also changes at this boundary and becomes extremely flat in the Lake zone. The Moiki, Lower Ruamahanga and Lake zones form a continuous flow system from the unconfined aquifers of the Ruamahanga valley to the deep confined aquifers in the Lake basin.

Principal surface water system: Ruamahanga River.

Aquifer sequences: Shallow unconfined aquifer to 0 to 15 m depth; southerly deepening semi-confined aquifer to 35 to 40 m depth.

Recharge: Average annual recharge is 0.2 x 10^6 m^3.

Existing RFP zones: Tawaha, Lower Valley (small northern part only). See Table F10.

Existing RFP allocation: See Table F10

Table F10: 'Safe yield' estimates and current groundwater allocation status for existing RFP (WRC 1999) groundwater zones within the Lower Ruamahanga water management zone

Existing RFP zone	RFP 'safe yield' (m^3/year x 10^6)	Current allocation (m^3/day)	% allocated
Tawaha	11.0	56,507	100
Lower Valley (aquifer 2)	13.5	67,697	91

F.8.2 Current Lower Ruamahanga zone allocation

As at June 2010, there were 23 bores with consented abstraction in the Lower Ruamahanga zone – three of these are public water supply bores for Martinborough and abstract throughout the year. The remainder are for irrigation use. The total allocation from the zone is 66,824 m^3/day.

F.8.3 Hydrogeology summary

The Lower Ruamahanga zone hosts a highly dynamic unconfined to semi-confined (Q1–Q4) aquifer system comprising permeable late Quaternary gravels some 10 to 20 m thick. The aquifer exhibits a high degree of connectivity with the Ruamahanga River. High volume groundwater abstractions occur from an unconfined Q2+Q4 gravel-rich aquifer which gradually deepens down-valley to a depth of about 40 m where it becomes semi-confined in the south-western part of the zone. The down-valley boundary of the zone marks the approximate point where the Q2+Q4 gravel-rich unit seggregates into two separate confined aquifers that continue into the Lake basin.

Near-surface (to c. 20 m depth) Holocene lake sediments extend up-valley into Lower Ruamahanga zone to form the semi-confining wedge above the Q2+Q4 aquifer which thickens toward the southern zone boundary. These capping deposits are ‘leaky’ and contain intermittent gravel lenses associated with abandoned channels of the Ruamahanga River.

Figure F46 shows a cross section along the axis of Ruamahanga valley to illustrate the aquifer geometry of this zone and the relationships between the three zones down the valley.

The Lower Ruamahanga zone receives throughflow from the up-valley Moiki zone and minor throughflow from the Martinborough and Dry River zones. The Ruamahanga River is a recharge source to the deepening Q2 +Q4 aquifer particularly where it is shallow and unconfined in the upstream part of the zone. Throughflow into the Lake zone aquifers, despite the continuity of the Q2 and Q4 aquifers across the Lower Ruamahanga/Lake zone boundary, is relatively small due to the flattening of the hydraulic gradient in the Lake zone. The Lower Ruamahanga zone is therefore regarded to contribute recharge to Lake zone confined aquifers, although modelling shows that the Tauherenikau zone is the predominant recharge source. However, modelling also indicates that abstraction from the Lake basin confined aquifers is likely to induce additional recharge from this zone and cause significant depletion effects in the Ruamahanga River.

Rainfall infiltration also contributes recharge to this zone together with throughflow inputs and river bed losses. The principal discharge mechanism is discharge back into the Ruamahanga River, with only minor throughflow into the Lake zone as discussed above.

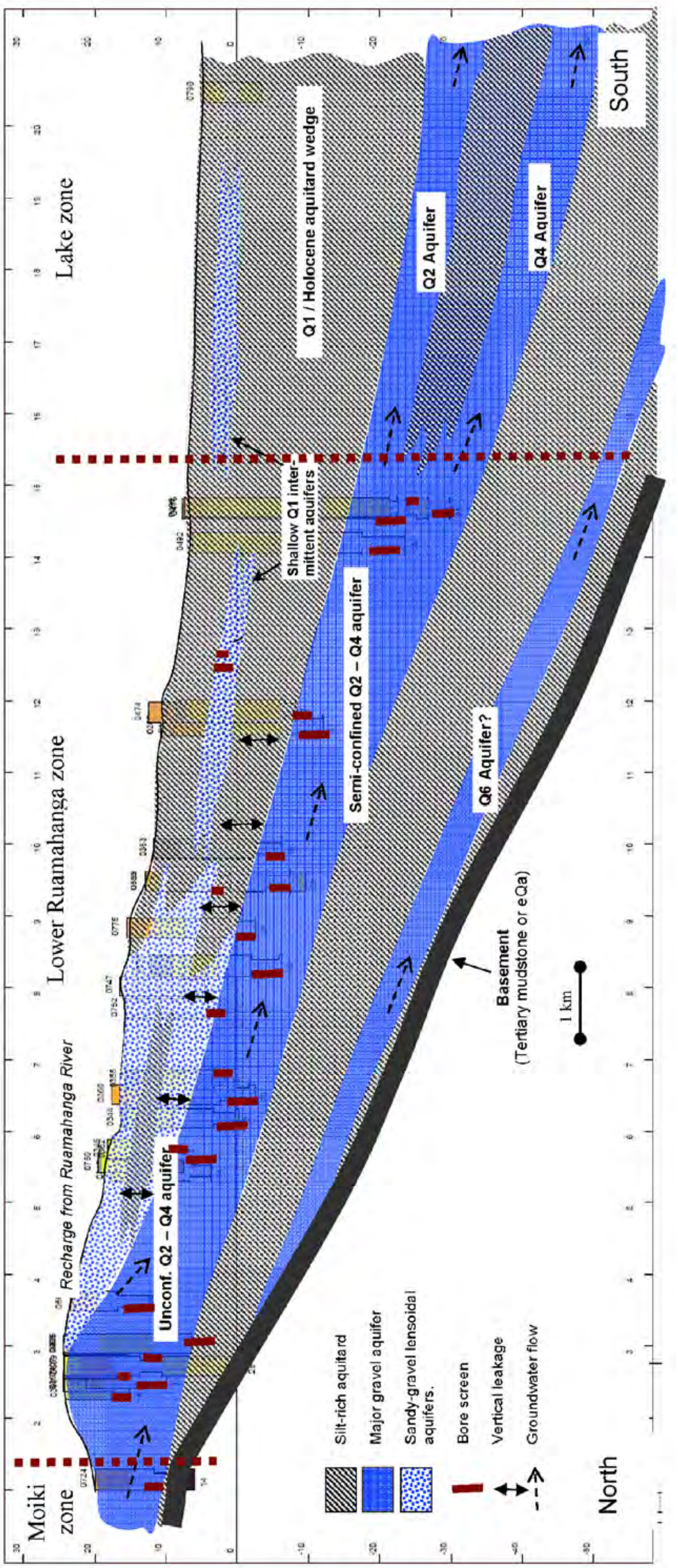

Figure F46: Schematic hydrogeological section along the axis of the Ruamahanga valley to illustrate aquifer geometry and the relationship between the Moiki, Lower Ruamahanga and Lake zones

F.8.4 Hydrology

Flows in the lower Ruamahanga River are monitored at Waihenga bridge (just below the Huangarua River confluence) where the calculated MALF (7-day) is reported to be 8.77 m^3/s (Cawthron 2008).

Within the Lower Ruamahanga zone, the Ruamahanga River exhibits a complex pattern of flow gain and loss. A concurrent gauging run conducted in February 2006 showed a flow loss of about 60,500 m^3/day (700 L/s) between Waihenga Bridge and Walls (in the centre of the zone – see Figure F45 for gauging locations) – notwithstanding the large gauging error. Between Walls and Pukio, the river then gained a flow of about 600 L/s, before entering another losing reach between Pukio and Awaroa sill where it lost about 600 L/s to groundwater.

F.8.5 Zone management objective

The principal management objective for groundwater allocation in the Lower Ruamahanga zone is to ensure the sustainable use of groundwater resources while protecting the instream values of hydraulically connected surface water ecosystems.

Within the Lower Ruamahanga zone, only the Ruamahanga River has a direct connection to the groundwater environment and the protection of baseflow in this river is therefore of primary importance.

F.8.6 Numerical modelling

The calibrated groundwater model for the Lower Valley catchment was used to assess the sustainability of current groundwater abstractions and to develop sustainable allocation options for the Lower Ruamahanga water management zone. Details of the model and its calibration are provided by Gyopari and McAlister (2010c).

Baseline (no-abstraction) water balance

The numerical groundwater flow model was used to quantify the natural water balance for the Lower Ruamahanga zone by running the model for a period of 16 years (1992 to 2008) with no abstraction occurring. This scenario provides a baseline simulation against which the effects of abstraction can be evaluated. Of particular relevance to assessing the sustainability of abstraction, the model provides information on the cumulative depletion effects of groundwater pumping on the Ruamahanga surface water environment.

The principal water balance components for the Lower Ruamahanga zone are rainfall recharge, positive and negative fluxes between groundwater and the Ruamahanga River, abstraction, and throughflow into and out of the zone to/from adjacent zones.

Figure F47 shows the modelled annual rainfall recharge for the Lower Ruamahanga zone for the period 1992 to 2007. The average annual rainfall recharge for this period is 1.31×10^6 m^3, although it is noted that there is a very high variability in annual recharge and in dry years estimated rainfall recharge may comprise a minor component of the overall aquifer water budget. The lower quartile annual recharge may therefore be a more appropriate measure of annual recharge which is calculated to be just 101,500m^3/year).

Abstraction from the Lower Ruamahanga zone was simulated for the 16-year transient model run and is shown in Figure F48. Estimated seasonal abstraction now peaks at approximately 52,000 m^3/day (based on metering data). The current consented abstraction is 66,800 m^3/day and therefore peak daily use may reach 80% of the maximum consented rate (although total seasonal use may be a considerably lower percentage of the overall consented volume).

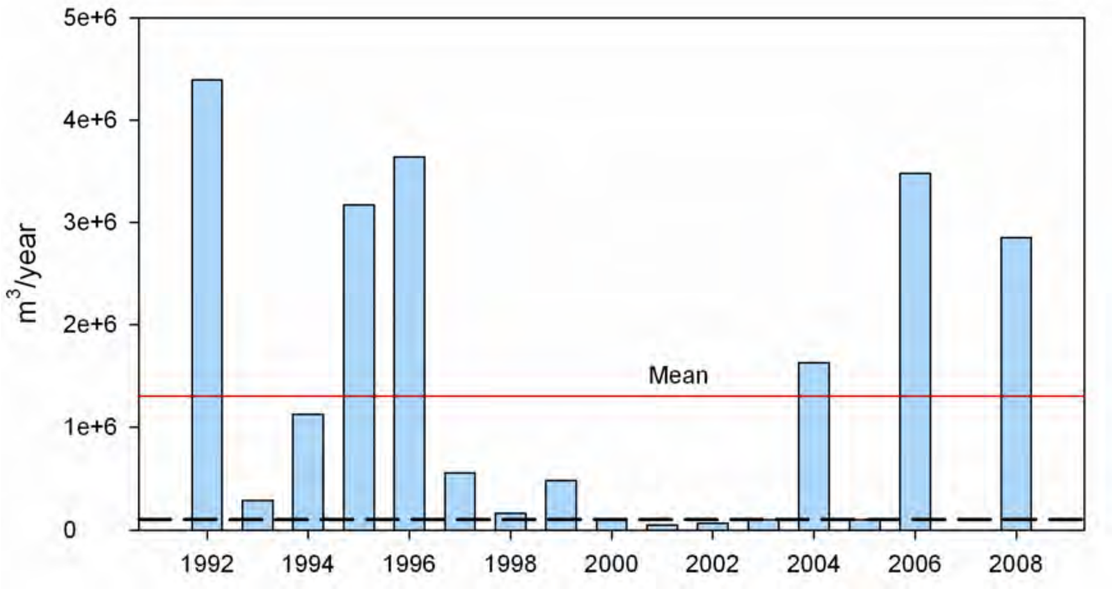

Figure F47: Modelled annual rainfall recharge over 16 years (1992 to 2008) for the Lower Ruamahanga zone (mean annual recharge is 1.3 x 10^6 m^3 and annual lower quartile recharge is 0.1 x 10^6 m^3)

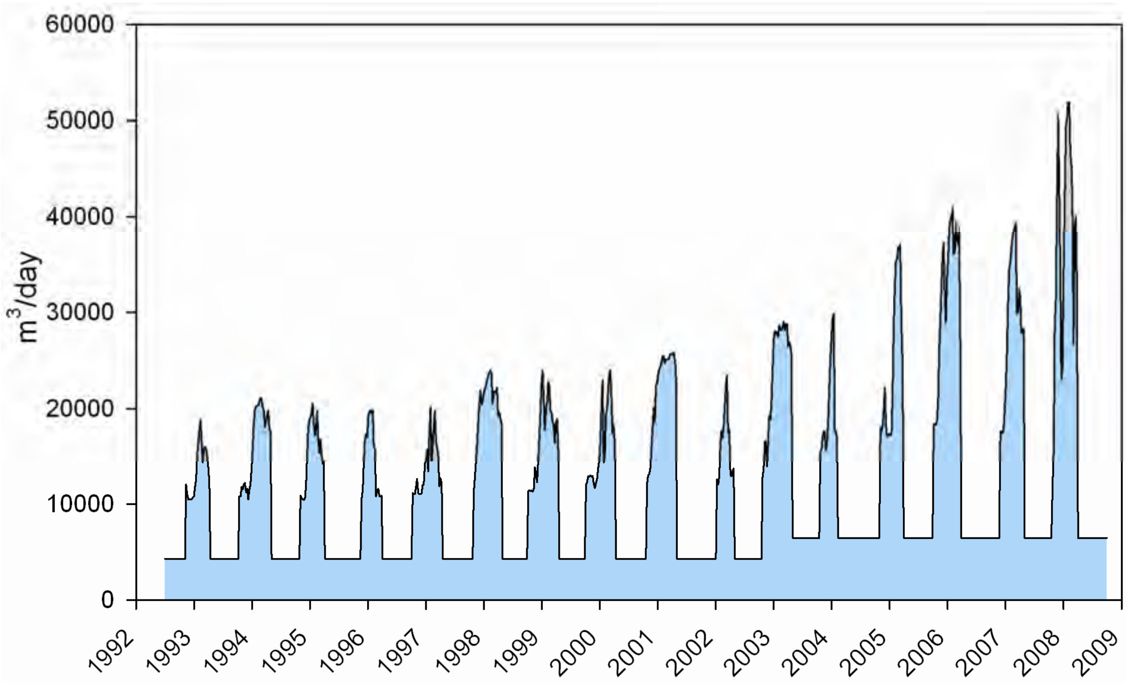

Figure F48: Simulated historic abstraction (1992–2008) in the Lower Ruamahanga zone from 23 bores. The 2007/08 peak abstraction rate is based on metering data and is about 80% of the maximum daily consented abstraction rate.

Modelled river fluxes in the absence of groundwater abstraction are shown in Figure F49. The model predicts a mean flow loss to groundwater from the Ruamahanga River of about 70,000 m^3/day (800 L/s) in the Lower Ruamahanga zone compared to an overall flow gain of approximately 120,000 m^3/day. As a result numerical modelling indicates a net flow gain in the Ruamahanga River of approximately 50,000 m^3/day (580 L/s) across the zone, with losses being higher in summer.

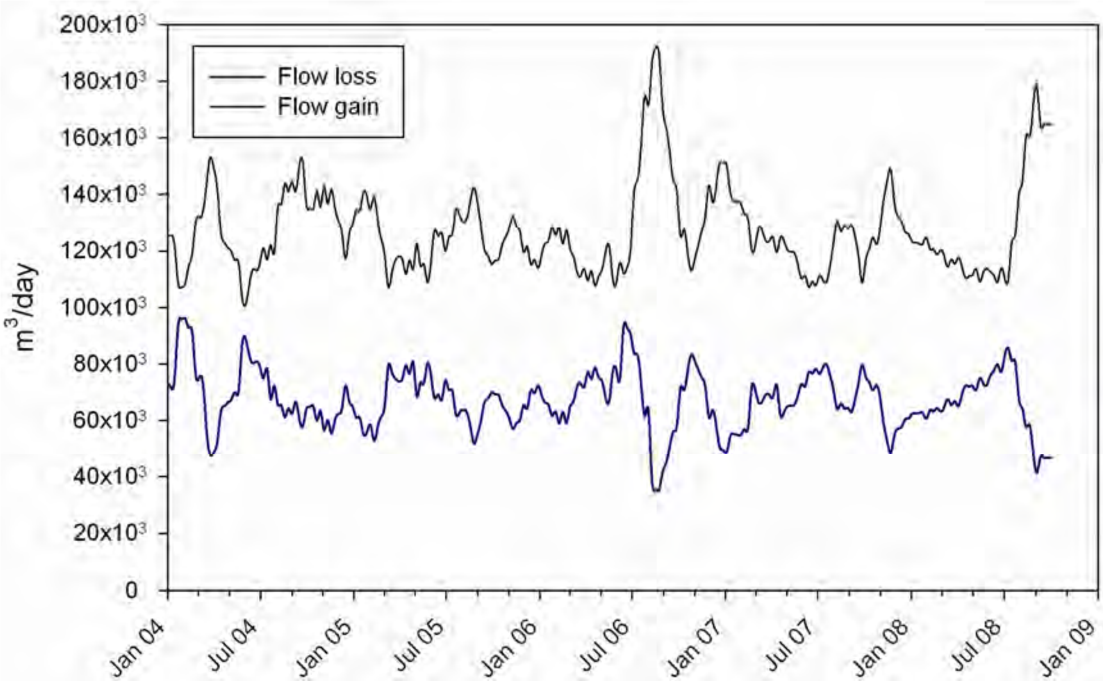

Figure F49: Simulated flow loss and gain from the Ruamahanga River in the Lower Ruamahanga zone when there is no groundwater abstraction. Losses are higher during summer and early winter when groundwater levels are lowest and therefore the vertical hydraulic gradient beneath the river bed is steepest.

Simulated aquifer throughflows into and out of the Lower Ruamahanga zone are shown in Figure F50 (no abstraction scenario). One of the largest throughflow inputs is from the Moiki zone which is estimated to be at least 25,000 m^3/day (290 L/s) during summer. Throughflow across the Martinborough Fault (from the Martinborough and Dry River zones) inputs 20 to 25,000 m^3/day and is highly dependent upon rainfall recharge trends.

A small outflow into the downstream Lake zone (tending towards zero in summer) is simulated. The very flat hydraulic gradients across the zone boundary in the Lake zone account for such low throughflow. However, as previously discussed, greater throughflow quantities are induced into the Lake zone when abstraction is occurring from Lake zone aquifers (see Section F.4.5).

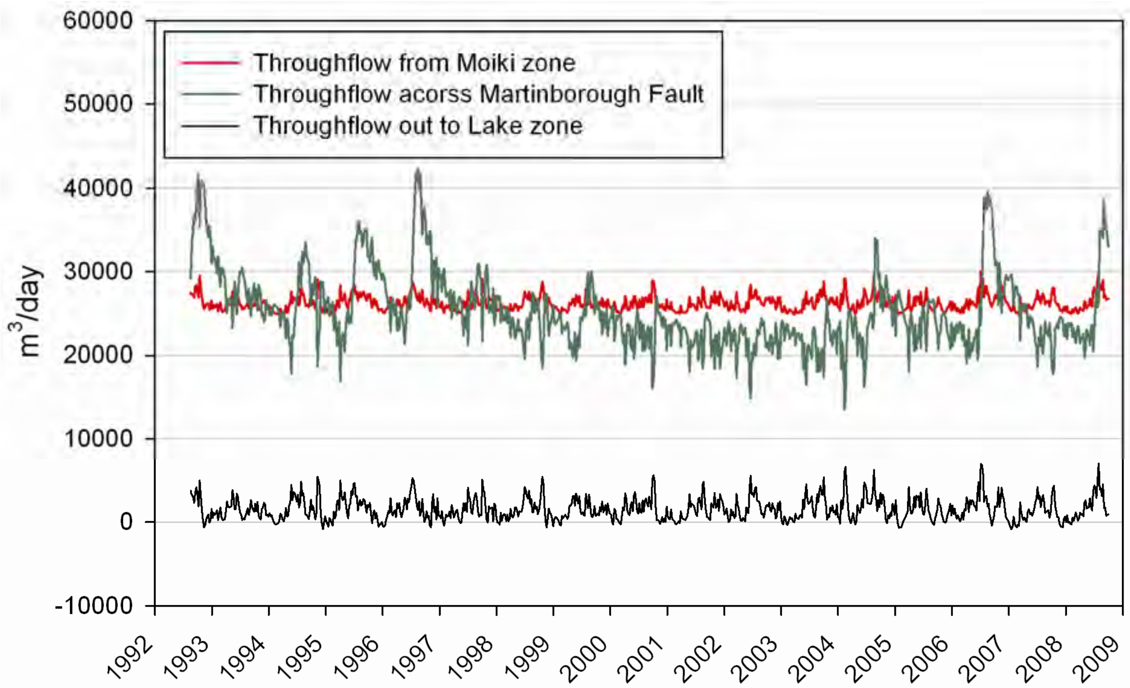

Figure F50: Simulated throughflow into and out of the Lower Ruamahanga zone in the absence of groundwater abstraction for the period 1992 to 2008

Simulated depletion effects

The depletion effects resulting from Lower Ruamahanga zone abstraction have been assessed using two model scenarios:

Scenario 1: Current (estimated) abstraction with all Lower Valley bores pumping for the 16-year transient model run (the calibrated model). In this scenario, all bores in the Lower Valley catchment (including the Lower Ruamahanga and adjacent water management zones) are pumping and therefore cross-zone interference effects are represented.

Scenario 2: A copy of the calibrated model in which only those bores in the Lower Ruamahanga zone are pumping (all other abstractions switched off). The run duration was also shortened to 2 June 2004 to 1 October 2008 (four irrigation seasons). This scenario is intended to isolate the effects of pumping from the Lower Ruamahanga zone only.

For both scenarios, the water balance outputs were compared to baseline (no-abstraction) simulations to observe the effects of abstraction on the surface water environment and throughflows (by comparing the two sets of water balance outputs). Flux balances for the following surface water systems were extracted from the model for the abstraction and no-abstraction scenarios (note many of these are located in the recharge area of the confined Lake zone aquifers):

- Ruamahanga River
- Throughflow to the Lake zone
- Throughflow across the Martinborough Fault
- Throughflow from the Moiki zone

Scenario 1

The current (estimated) abstraction was simulated for the 16-year transient model run and the water balance outputs were compared to a baseline (no-abstraction) simulation. The effects of groundwater abstraction on the surface water environment were then quantified by comparing the two sets of water balance outputs. Figure F51 shows the simulated surface water depletion in the Lower Ruamahanga zone together with the seasonal abstraction rates.

During all irrigation seasons is it apparent that the river depletion rate is equivalent to the abstraction rate suggesting a directly connected groundwater and surface water environment in this zone. Figure F52 shows that the depletion rate rapidly attains the abstraction rate with minimal lag, and rapidly declines when pumping stops. This plot provides justification that groundwater takes in this zone exhibit a direct hydraulic connection with the Ruamahanga River and therefore are most appropriately managed in terms of the Category A classification.

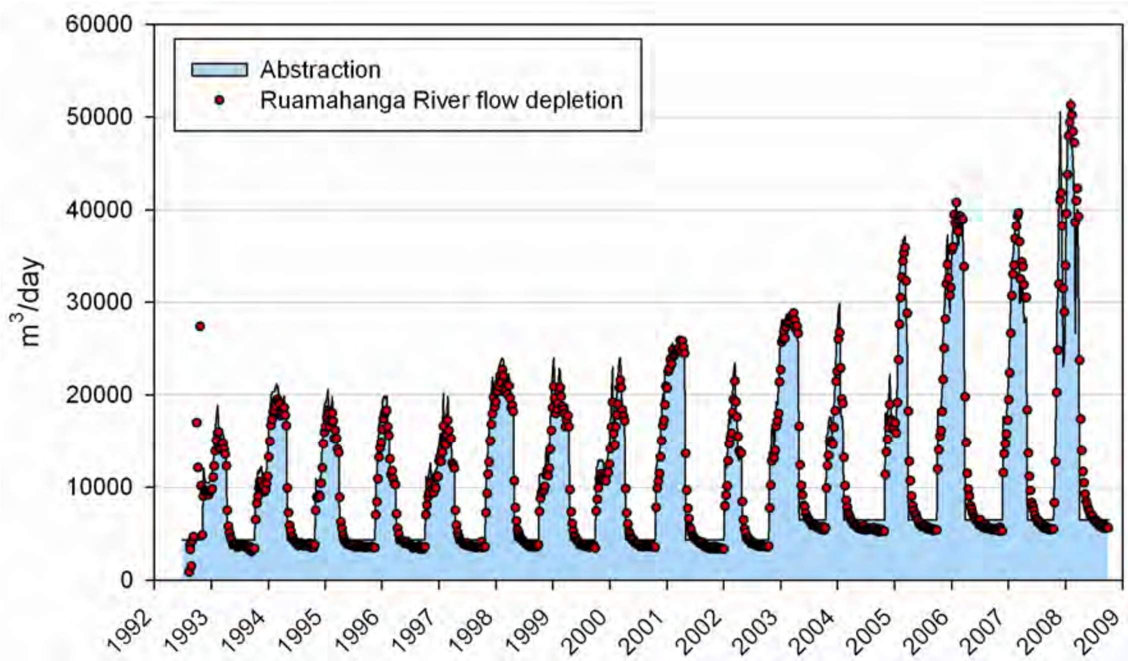

Figure F51: Scenario 1 – simulated flow depletion in the Ruamahanga River in the Lower Ruamahanga zone resulting from historic abstraction (1992 to 2008). Also shown is the abstraction rate for the Lower Ruamahanga zone only. It is clear that depletion is equivalent to abstraction showing the highly connected nature of the groundwater and surface water environments in this zone.

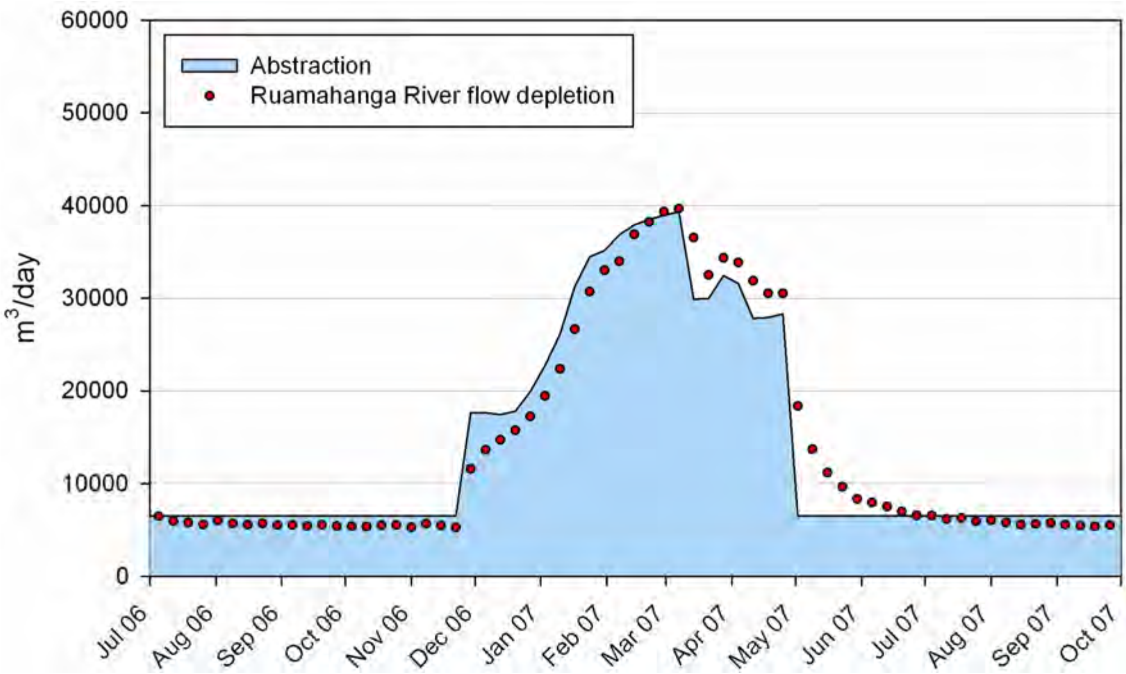

Figure F52: Scenario 1 – Simulated flow depletion in the Ruamahanga River in the Lower Ruamahanga water management zone over the 2006/07 irrigation season, illustrating the high degree of hydraulic connection between the river and aquifer

Figure F53 shows the changes in throughflow into and out of the Lower Ruamahanga zone as a result of abstraction in all zones. These data show there is a marked increase in throughflow out of the zone and into the Lake zone as a result of abstraction drawdowns in the confined Lake zone aquifers propagating up the Ruamahanga valley (see Section F.4). During the 2007/08 irrigation season the modelled increase in throughflow from the Lower Ruamahanga zone into the Lake zone was approximately 3,000 m^3/day, equivalent to approximately 13% of the total abstraction rate from the Lake zone (refer also to Table F2 and Section F.4).

Figure F53 also shows an induced throughflow into the Ruamahanga zone from the Moiki zone of 1,000 to 1,200 m^3/day as a result of the modelled abstraction. Throughflow across the Martinborough Fault initially showed an increase between 1992 and 2000, but when abstraction in the Martinborough and Dry River zones commenced in 2001 there was a seasonal reduction in throughflow across the fault into the Lower Ruamahanga zone. It is interesting to note that the reduction in throughflow from the Martinborough zone is only up to about 1,000 m^3/day, whereas the total depletion across the fault exceeds 3,000 m^3/day, the balance being attributed to abstraction from the Dry River zone which clearly has a greater connection to the Lower Ruamahanga zone.

It appears that the increased throughflow from the Moiki zone and decreased throughflow across from the Martinborough zone approximately balance each other. Therefore, the induced throughflow to the Lake zone and reduced throughflow from the Dry River zone only should be taken into account when determining an allocation scheme for the Lower Ruamahanga zone. An additional ‘take’ of 0.13 x Lake zone abstraction from the Lower Ruamahanga zone is therefore included to account for the effect of abstraction from the Lake zone. The larger throughflow depletion effects of abstraction from the Dry River zone can be accounted by assigning takes in this zone as a Category B whereby the abstractions are referenced to flow in the Ruamahanga River.

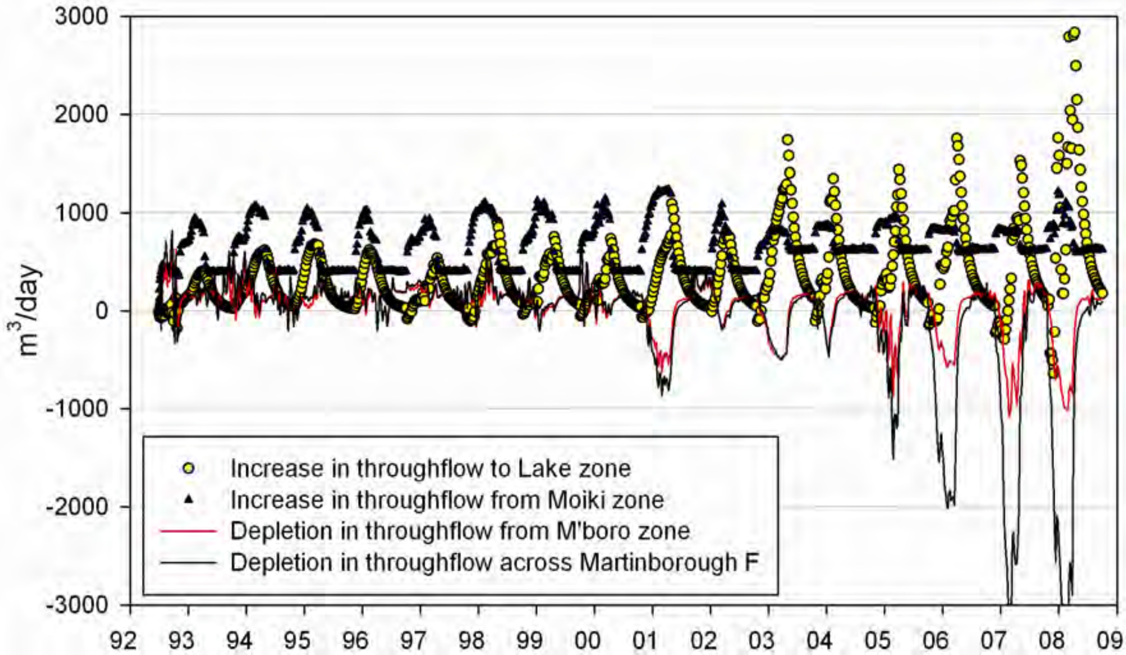

Figure F53: Scenario 1 – simulated changes between 1992 and 2008 in throughflow into and from the Lower Ruamahanga zone when abstraction occurs from all zones

Scenario 2

Scenario 2 is a short-run simulation (2004 to 2008) in which only bores in the Lower Ruamahanga zone are pumping, thereby isolating the pumping effects associated with abstraction solely from this zone. This scenario was undertaken to confirm whether the entire zone can be considered as directly connected to the Ruamahanga River and that groundwater abstractions have an immediate impact on river flow. Figure F45 shows the location of abstraction bores which are distributed relatively evenly across the zone within the Q2+Q4 aquifer.

Figure F54 shows the simulated depletion effects on the Ruamahanga River within the Lower Ruamahanga zone for the period 2004 to 2008. This plot shows that modelled river depletion is very responsive to pumping and rapidly attains 80 to 90% of the seasonal pumping rate (i.e. time lags are small). This result indicates storage utilisation in this zone is relatively small with water being drawn almost immediately from the river. The differences between Figure F54 and F51 relate to the effects of pumping from neighbouring zones which increases the depletion effect to 100% of the abstraction rate. Both plots provide good justification for classifying the entire Lower Ruamahanga water management zone as a Category A (direct hydraulic connectivity) area.

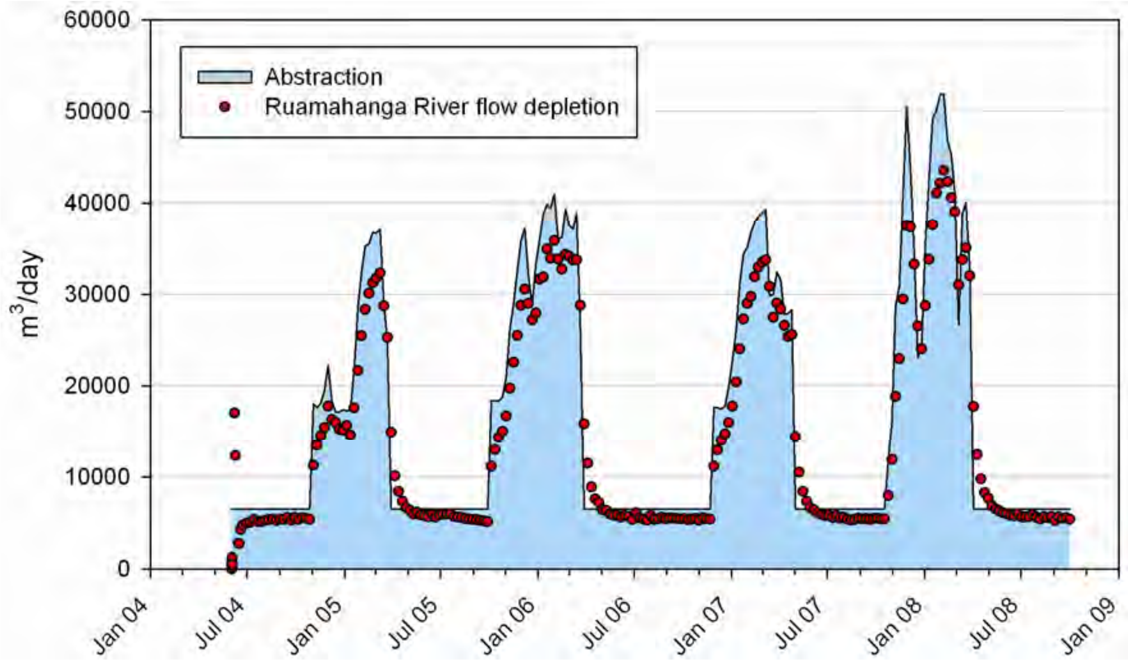

Figure F54: Scenario 2 – simulated in-zone Ruamahanga River depletion with abstraction only from Lower Ruamahanga zone.

F.8.8 Groundwater management options for the Lower Ruamahanga water management zone

Groundwater-surface water interaction zones

- Due to the high degree of connection between the Lower Ruamahanga zone aquifers and the Ruamahanga River, all aquifers this zone (Q1, Q2, Q4) should be classified as Category A (direct hydraulic connectivity). This includes shallow unconfined Q1 aquifers and the deeper semi-confined Q2+Q4 aquifer.

- Increased throughflow out of the zone resulting from Lake zone abstraction should be taken into consideration when allocating water from the Lower Ruamahanga zone. An additional abstraction from the Ruamahanga River of 0.13 x Lake zone allocation should be adopted.

Groundwater allocation

- No allocation limit is required in this zone since all takes will be regulated according to the Category A classification.

- The reduction in throughflow to the Ruamahanga zone from the Dry River zone should be accounted for through the assignment of the Dry River zone as a Category B (high hydraulic connectivity) area.

F.9 Dry River water management zone

F.9.1 Overview

Delineation: The Dry River water management zone is a geologically and hydrogeologically distinct area located south of the Martinborough Fault and adjacent to the Martinborough zone (Figure F55) (although the aquifers identified in this zone are hydraulically connected with the neighbouring zones). Groundwater in this zone discharges north-westwards into the Lower Ruamahanga zone.

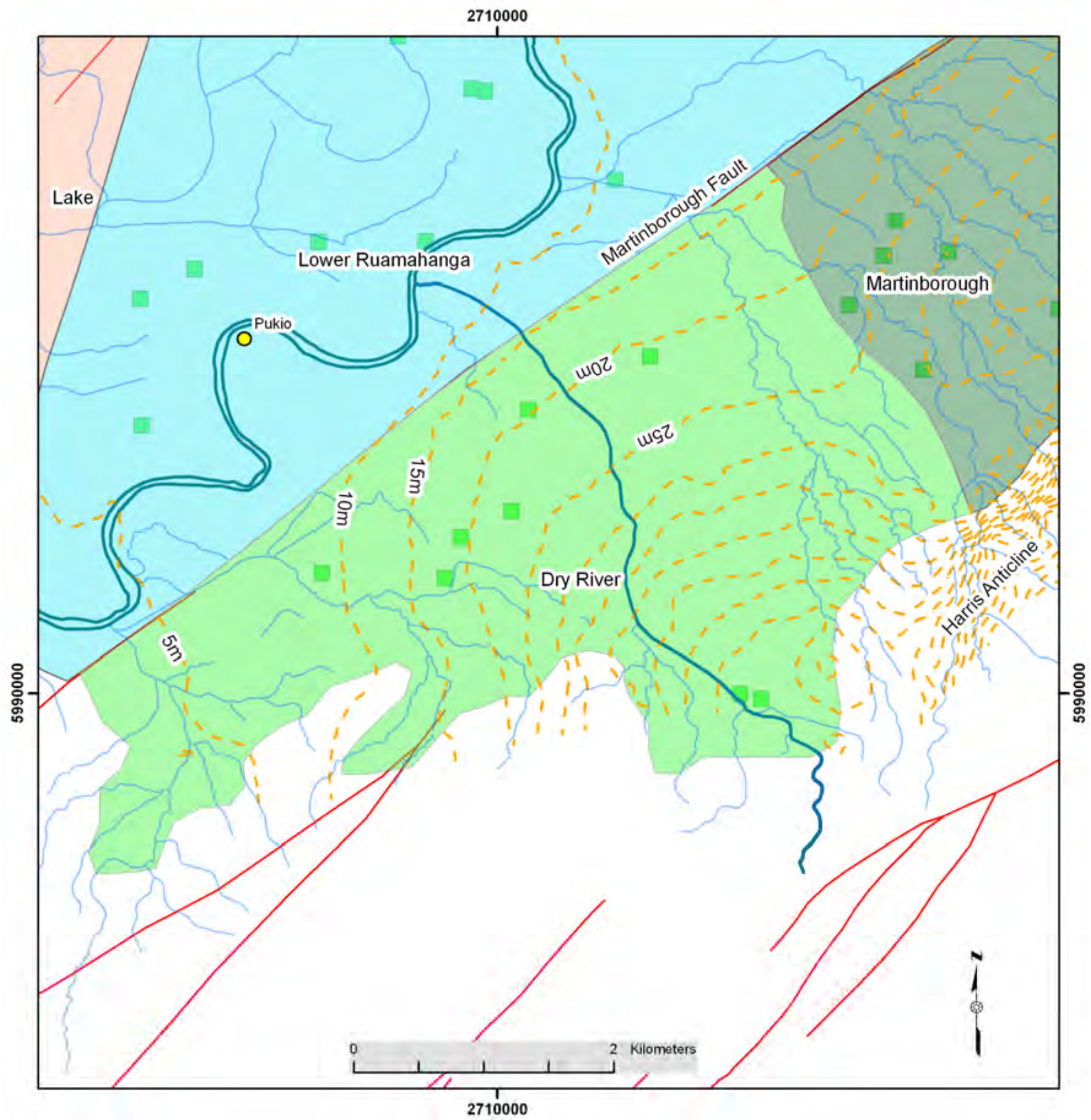

Figure F55: The Dry River water management zone showing existing groundwater bores with consented abstraction (green squares), groundwater flow contours (brown dashed lines) and neighbouring zones

Area: 16.7 km^2.

Boundaries: The north-western boundary is aligned with the Martinborough Fault which offsets to geological sequence but does not constitute a flow barrier within shallower aquifers.

The north-eastern boundary marks the mapped edge of younger Holocene age sediments against older Q4 age deposits of the Martinborough water management zone.

The southern boundary follows the contact between the late Quaternary/Holocene sequence with the Tertiary sediments of the eastern hills.

Principal surface water systems: Dry River

Aquifer sequences: Shallow unconfined fan deposits (<10 m)
Semi-confined Q2-Q4 aquifer 20 to 30 m deep (Q4/6)

Recharge: Estimated average annual rainfall recharge is 1.6 x 10^6 m^3 (4,380 m^3/day)

Existing RFP zones: Parts of the following RFP (WRC 1999) zones fall in the Dry River zones: Martinborough Western Terraces, Tawaha, Pirinoa Terraces, Lower Valley.

Existing allocation: As at June 2010, there were eight groundwater bores with consented abstraction in the Dry River zone (see Figure F55) with a total daily allocation of 7,253 m^3/day. All bores (except for two very shallow bores in the upper reaches of the Dry River) abstract from a (Q2–Q4) semi-confined aquifer at 20 to 40 m depth.

F.9.2 Hydrogeology summary

The Dry River area comprises a mantle of young Holocene fluvial material associated with the Dry River. Beneath these deposits, the late Quaternary sequence is regarded to be continuous with the adjacent Martinbough zone deposits although sediment inputs from the Dry River probably amalgamate into this sequence. The principal aquifer comprises Q2–Q4 gravels which form a semi-confined system which ultimately discharges to the Lower Ruamahanga zone.

The Dry River zone is recharged from rainfall infiltration and from flow losses from the Dry River.

F.9.3 Hydrology

The Dry River drains a small catchment (36 km^2) in the northern Aorangi Range and joins the Ruamahanga River about 6 km south west of Martinborough. The limited river flow data available is insufficient to enable reliable estimation of flow statistics for this river. Dry River has a high gravel load and lives up to its name, often drying up over a significant proportion of its length during low rainfall periods. The modelled loss of flow from Dry River into the adjacent aquifer peaks at approximately 150 L/s in summer when the hydraulic gradient between the river and the adjacent aquifer is highest (note however that this quantity is not able to be verified by actual flow data).

F.9.4 Zone management objective

Dry River is the only surface water system in this zone apart from ephemeral runoff streams. However, little is known about the hydrology of this stream, which routinely runs dry during summer. The principal objective for groundwater allocation in the Dry River zone is therefore to ensure the sustainable use of groundwater resources by having specific regard to:

- Rainfall recharge; and
- Interference effects on existing groundwater users.

Interference effects on existing groundwater users will be addressed by specific policy rules. Therefore, given the hydrology of the Dry River catchment, allocation volume for this zone should be based on a sustainable proportion of the annual rainfall recharge.

F.9.5 Numerical modelling

Zone water balance

The numerical groundwater flow model was used to quantify the natural water balance for the Dry River zone by running the model for a period of 16 years (1992 to 2008) with no groundwater abstraction occurring. The principal water balance components for the zone are: rainfall recharge, throughflow to the Lower Ruamahanga zone, groundwater abstraction and leakage from the Dry River.

Figure F56 shows the modelled annual rainfall recharge for the period 1992 to 2008 derived from soil moisture balance modelling. The average annual recharge for the zone is calculated to be 1.6×10^6 m^3, although it is noted that actual recharge may be very low in dry years. The lower quartile annual recharge is about 760,000m^3 which equates to about 50% of the mean annual recharge. For details on climate and recharge modelling methodology refer to Gyopari and McAlister (2010c).

The simulated throughflow to the Dry River zone into the Lower Ruamahanga zone across the Martinborough Fault is shown in Figure F57. The throughflow trend is strongly influenced by temporal variations in rainfall recharge with the effects of the low-rainfall period between 1997 and 2003 being reflected in calculated reductions in throughflow during this period.

The mean summer throughflow is approximately 14,000 m^3/day which equates to the mean summer discharge from the Dry River of about 160 L/s (Figure F58).

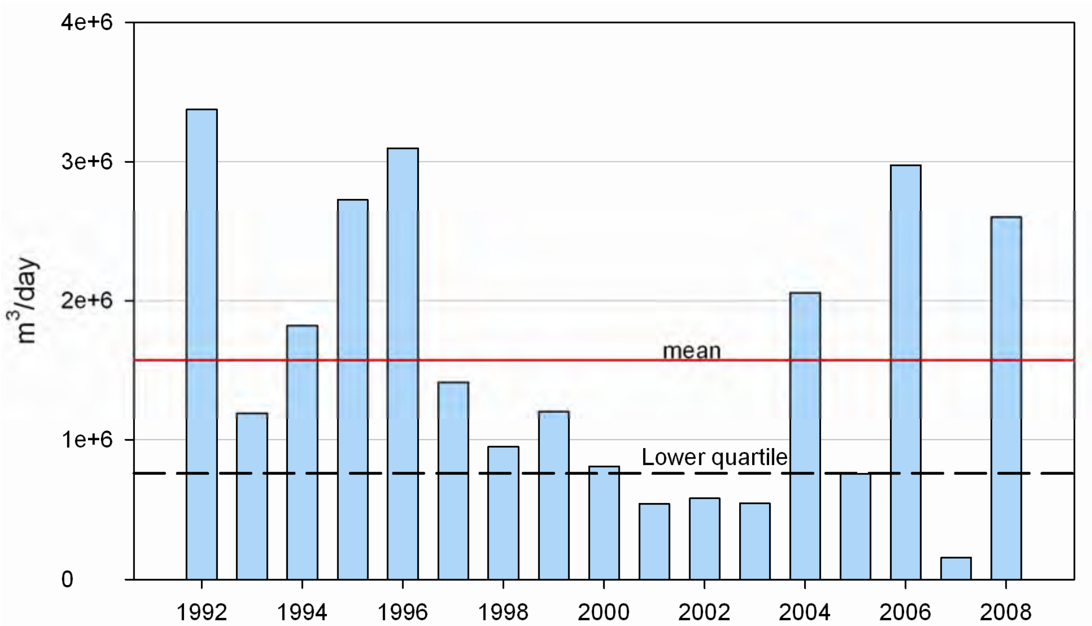

Figure F56: Modelled annual rainfall recharge for the Dry River zone (mean annual recharge is 1.6×10^6 m^3 and the lower quartile annual recharge is 0.76×10^6 m^3 for the period 1992 to 2008)

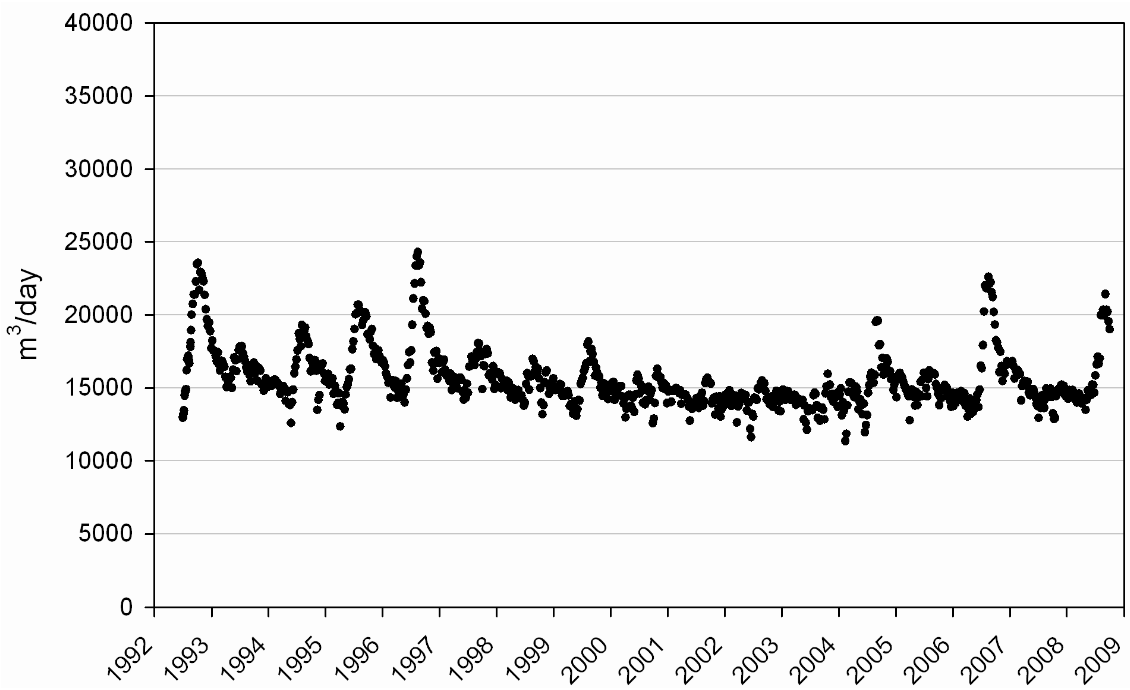

Figure F57: Simulated throughflow westwards into the Lower Ruamahanga zone for the period 1992 to 2008 when there is no groundwater abstraction. The long-term trend reflects climate and recharge variability. The mean summer throughflow for this period is 14,000 m^3/day (162 L/s).

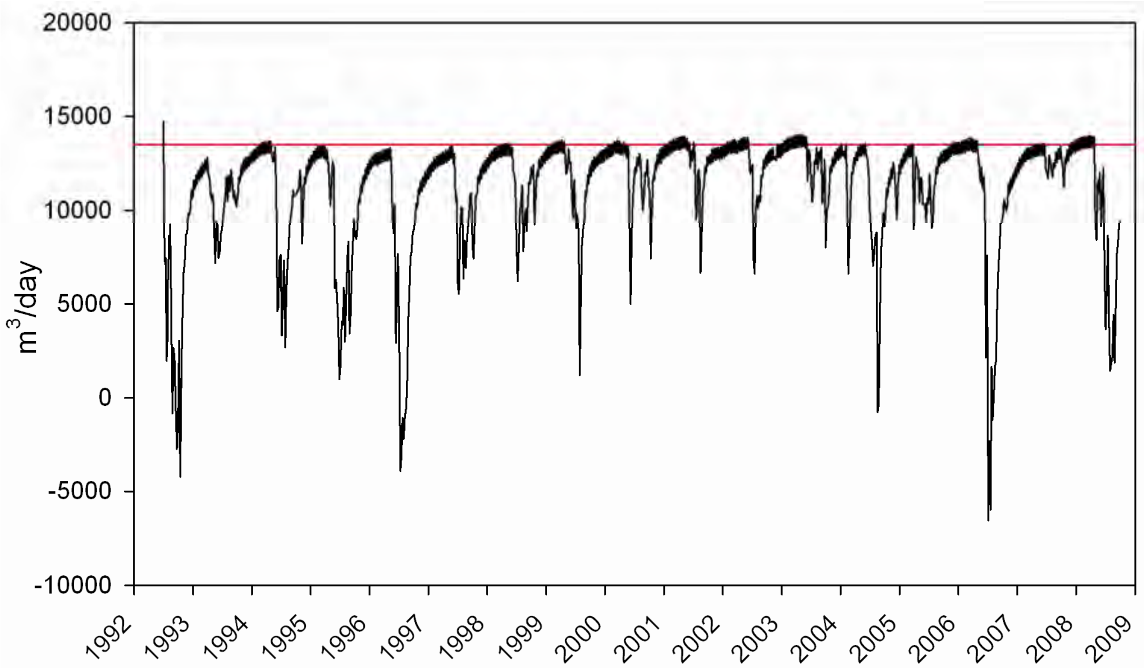

Figure F58: Simulated leakage through the bed of the Dry River, 1992–2008. Mean summer discharge is about 13,000 m³/day (150 L/s), shown by the red line.

As at June 2010, there were 8 bores with consented abstraction in the Dry River zone with a total abstraction rate of 7,300 m³/day. All but two of these bores abstract from the Q2–Q4 semi-confined aquifer between about 20 and 40 m depth. The actual abstraction has been modelled based upon annual metering data and is shown in Figure F59. Seasonal irrigation abstractions did not commence in this area until 2005/06

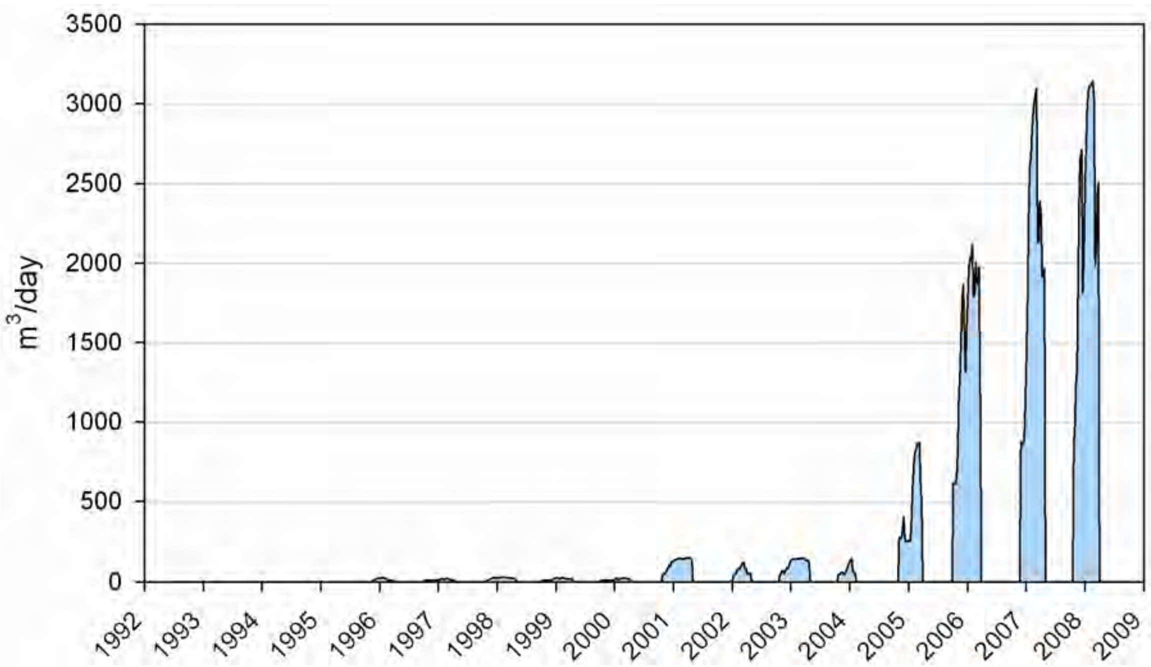

Figure F59: Simulated groundwater abstraction volume in the Dry River zone between 1992 and 2008 and the peak estimated abstraction during the 2007/08 irrigation season was approximately 3,100 m^3/day or around 42% of the consented rate. Since daily records are not available, the estimated daily use may be underestimated. Evidence from metering data elsewhere in the Wairarapa Valley suggests that the mean actual daily use is often 60 to 70% of the consented rate.

Pumping effects

The principal effects of groundwater abstraction from the Dry River zone is the reduction in throughflow to the adjacent (down-gradient) Lower Ruamahanga zone, and the inducement of greater leakage from the Dry River (should there be sufficient flow). Figure F60 shows the simulated depletion of throughflow across the Martinborough Fault. The summer depletion is approximately 90% of the cumulative pumping rate from the zone. The theoretical depletion of the Dry River is relatively minor, peaking at about 400 m^3/day (4 to 5 L/s) in 2007/08, or approximately 13% of the pumping rate.

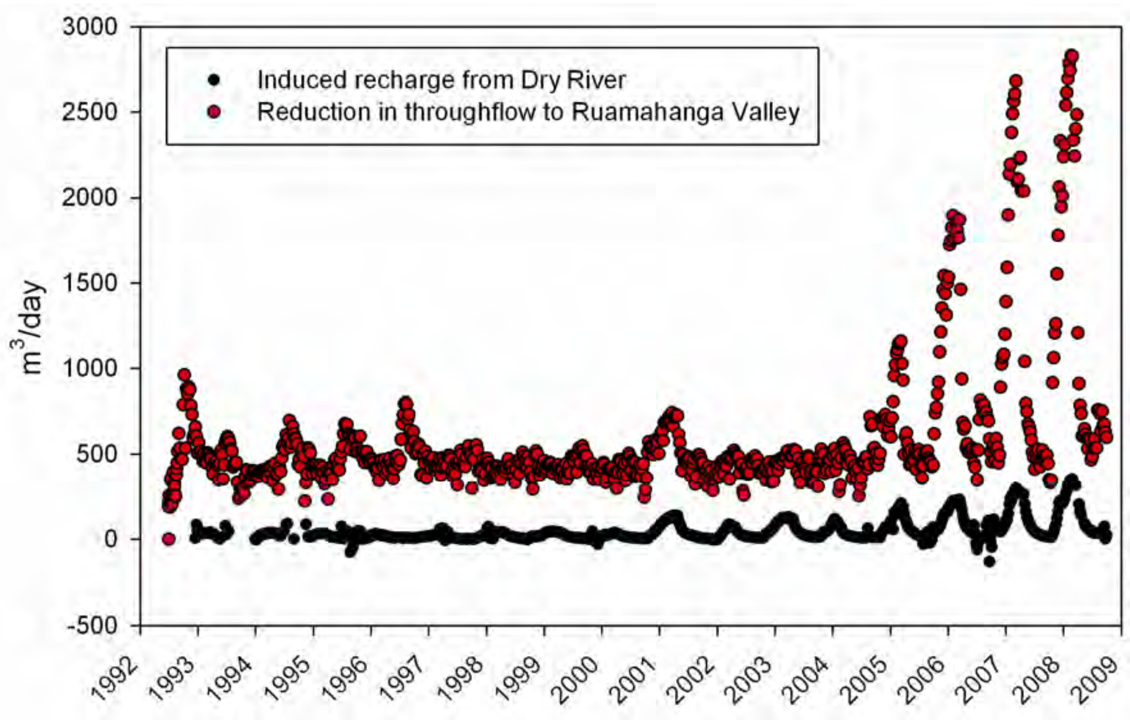

Figure F60: Simulated depletion in throughflow from the Dry River zone across the Martinborough Fault into the Lower Ruamahanga zone, and induced recharge from the Dry River. The throughflow depletion attains about 90% of the abstraction rate. Pumping is occurring in all Lower Valley water management zones during this simulation.

F.9.6 Groundwater management options for the Dry River water management zone

Groundwater-surface water interaction zones

- Since abstraction from the Dry River zone results in a significant reduction in throughflow to the Lower Ruamahanga zone (the model indicates a reduction equivalent to up to 90% of the cumulative pumping rate for the Dry River zone), a proportion of the abstraction from this zone should be assigned to the Lower Ruamahanga zone. This should be achieved by designating the Dry River zone as Category B (high hydraulic connection) area. Under this classification, a proportion of the abstraction would be assigned to the Ruamahanga River with the remainder counted as part of the groundwater allocation for the Dry River zone.

Groundwater allocation

- The aquifers in the Dry River zone should be managed as a single resource. Most abstraction occurs from the Q2–Q4 semi-confined more productive system.

- This zone is recharged from rainfall infiltration and losses from the Dry River. Since information on the hydrology of the Dry River is very limited, the numerical model and its predictions regarding the interaction between the river and groundwater cannot be verified. Allocation should therefore be referenced to rainfall recharge. The mean annual recharge has been calculated to be 1.6×10^6 m^3/year for the period 1992 to 2008.

- The annual recharge rate for the Dry River zone has a high standard deviation (see Figure F56). For the 1992 to 2008 period, the lower quartile annual recharge was 0.76×10^6 m^3/year or approximately 50% of the mean annual recharge. It is recommended that the annual allocation limit does not exceed 40-50% of the mean annual recharge rate.

- That allocation be expressed as an annual maximum and a weekly maximum. The weekly maximum should be based upon a 180 day irrigation season.

Table F11 outlines potential groundwater allocation options for the Dry River water management zone. Option 1 is recommended to take into account the frequent occurrences of successive dry years during which the LQLSR should not be exceeded.

Table F11: Allocation options for the Dry River water management zone based on a proportion of estimated annual rainfall recharge

Options	Allocation reference	Allocation (m^3/year x 10^6)	Allocation (m^3/day)
1	40% LSR (83% LQLSR)	0.63	3,500
2	50% LSR (100% LQLSR)	0.79	4,400
3	60% LSR (125% LQLSR)	0.95	5,300

*LSR = mean annual land surface recharge (rainfall recharge). LQLSR = lower quartile LSR

F.10 Huangarua water management zone

F.10.1 Overview

Delineation: The Huangarua water management zone occupies a NW-SE trending valley south of Martinborough which runs between the Harris Anticline and the Tertiary hill country. It is characterised by the late Quaternary valley-fill alluvium associated with the Huangarua River catchment. The elongate zone is 14 km long and between 500 m and 3 km wide.

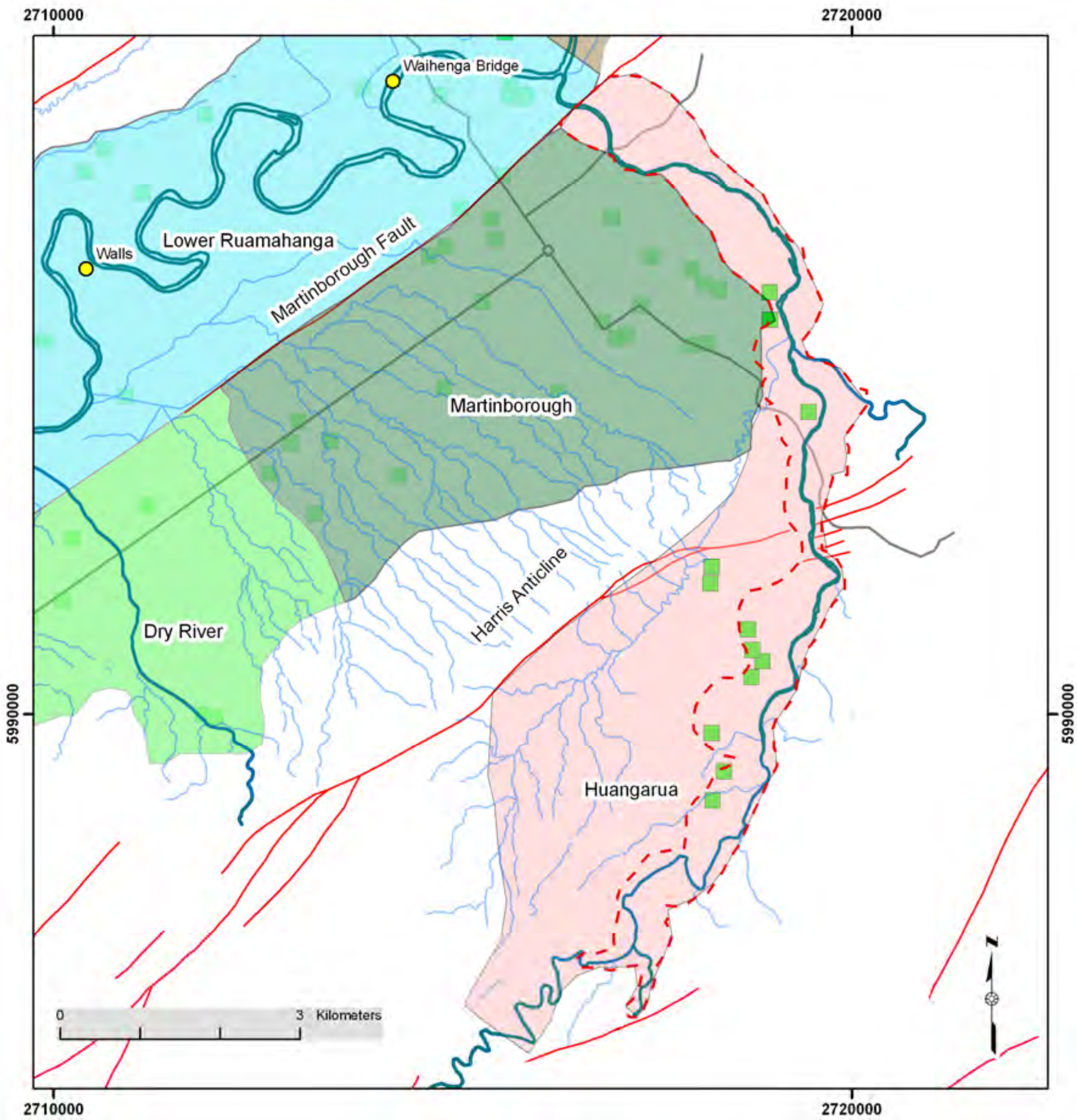

Figure F61: The Huangarua water management zone defined by the recent alluvium and Q2-4 terraces of the Huangarua River valley. The map shows existing groundwater bores with consented abstraction (green squares) and delineates the edge of lower terrace aquifers (red dashed line).

Area: 22.5 km^2

Boundaries: The zone boundaries are defined by the contact between Holocene/Quaternary valley fill alluvium and the adjacent elevated Tertiary hills and prominent Martinborough terrace edge. The zone extends down to the Martinborough Fault.

Principal surface water system: Huangarua River.

Aquifer sequences: Shallow Q1 unconfined aquifer and undifferentiated semi-confined aquifers 10 to 40 m depth.

Recharge: Estimated average annual rainfall recharge is 3.22 x 10^6 m^3 (8,820 m^3/day)

Existing RFP zones: Huangarua Upper Terraces, Huangarua Lower Terraces

Current allocation: As at June 2010, there are currently 12 bores with consented abstraction in the Huangarua zone (see Figure F61). Most abstractions are for vineyard irrigation with typical rates of less than 10 L/s (the largest abstraction being 26 L/s). The current total daily allocation outlined in Table F12 below is 10,769 m^3.

Table F12: Safe yield' estimates and current groundwater allocation status for existing RFP (WRC 1999) groundwater zones within the Huangarua water management zone

Existing RFP groundwater zone	RFP 'safe yield' (m^3/year x10^6)	Current allocation (m^3/day)	% allocated
Huangarua Upper Terraces	0.5	515	17
Huangarua Lower Terraces			
- Aquifer 1	0.9	2,133	42
- Aquifer 2	1.2	8,121	98

F.10.2 Hydrogeology summary

The low-lying recent floodplains of the Huangarua River are underlain by recent Q1 gravels and last glacial (Q2+) gravel-rich sequences associated with the river. The most productive aquifers in the valley occur in this area comprising a near-surface unconfined Q1 aquifer and an underlying heterogeneous semi-confined Q2+ aquifer system to about 35 to 45 m depth. Most bores in this zone abstract from the semi-confined system. Figure F61 shows the extent of the lower terrace sequences (dashed red line) which traces a terrace edge. Older Q3+ terrace sequences outcrop on the elevated valley sides (Te Muna Road area) and host relatively poor-yielding aquifers.

The Huangarua valley narrows to less than 800 m wide in the reach between the Martinborough Fault and the main road bridge. The alluvial (Q1) sediments appear to be very thin along this reach and bores are less than 5 m deep. Upstream of the bridge, the valley widens considerably and older elevated terrace sequences occur to the west of the river. The river hugs the eastern edge of the valley and follows the contact with the older Tertiary hills. The southern half of the zone is deformed by a synclinal structure.

The aquifers in this zone are recharged primarily from rainfall, although the Huangarua River probably interacts with the unconfined and semi-confined aquifers, particularly in the lower terrace area. However, there is little information with which to demonstrate this.

Further detailed hydrogeological information on the Huangarua Valley is provided by Butcher (2001)[36].

F.10.3 Hydrology

The Huangarua River is a major tributary to the Ruamahanga River, with the confluence 1.8 km north of Martinborough. The Huangarua River is sourced in the eastern Haurangi Range and has a total catchment area of 31.1 km^2. The river flows in a general northwards direction through a wide valley in a channel that is actively degrading into Holocene gravels. The 7-day MALF at the Ruamahanga confluence has been estimated at 360 L/s (Keenan 2009). There is anecdotal evidence that groundwater abstraction may have significantly influenced the low flow conditions in this river which are interpreted to have reduced by about 10% over the last decade (groundwater abstraction commenced in the valley in 2000).

F.10.4 Zone management objective

The principal objective of groundwater allocation in the Huangarua zone is to ensure the sustainable use of groundwater resources by having specific regard to the instream values of hydraulically connected surface water systems.

Within the Huangarua zone, only the Huangarua River has a direct connection to the groundwater environment and the protection of baseflow in this river is therefore of primary importance.

F.10.5 Numerical modelling

The calibrated groundwater model for the Lower Valley catchment was used to evaluate the water balance for the Huangarua zone. Because the model calibration could not be evaluated in this zone (due to the lack of monitoring data), the model has not been relied upon to assess river depletion effects. Details of the model and its calibration are provided in Gyopari and McAlister (2010c).

Baseline (no-abstraction) water balance

The numerical groundwater flow model was used to quantify the natural water balance for the Huangarua zone by running the model for a period of 16 years (1992 to 2008) with no groundwater abstraction occurring. This scenario provides a baseline simulation against which the effects of abstraction can be evaluated. Of particular relevance to assessing the sustainability of abstraction, the model provides information on the cumulative depletion effects of groundwater pumping on the Huangarua surface water environment.

The principal water balance components for the Huangarua zone are rainfall recharge, fluxes between the Huangarua River and groundwater, and abstraction.

[36] Butcher, G. 2001. *Groundwater resources of the Huangarua groundwater zone.* Report prepared for Wellington Regional Council.

Figure F62 shows the modelled annual rainfall recharge for the Huangarua zone for the period 1992 to 2008. The average annual rainfall recharge for this period is 3.22×10^6 m^3 (8,820 m^3/day) with a lower quartile annual recharge volume of 1.36×10^6 m^3 (3,720 m^3/day).

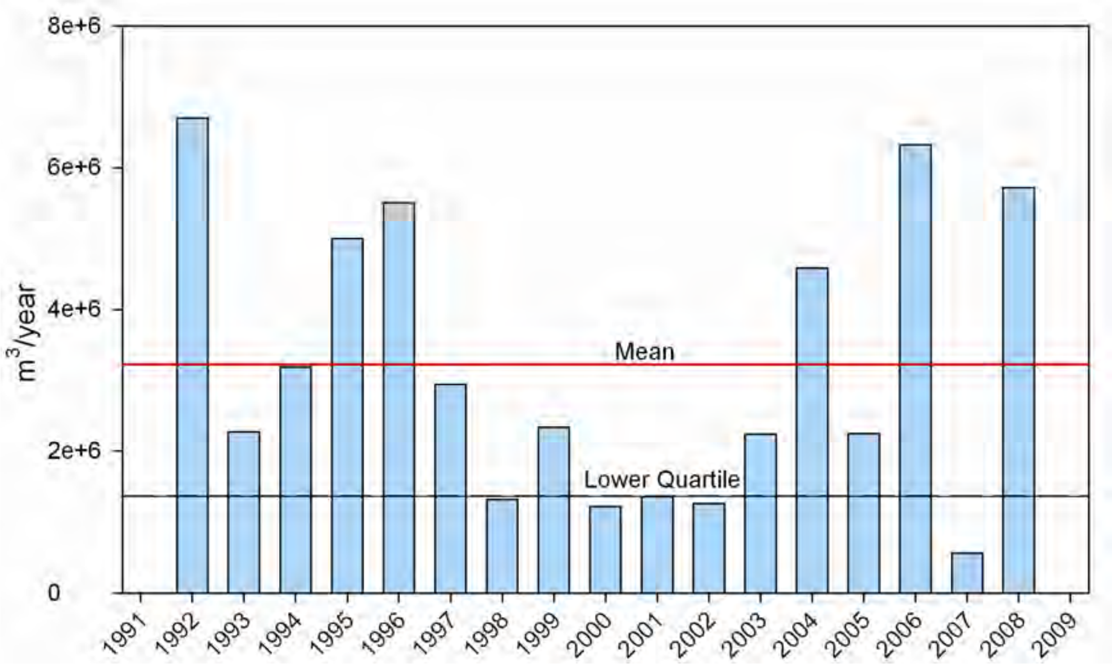

Figure F62: Modelled annual rainfall recharge for the Huangarua zone in the Lower Valley catchment

Abstraction from the Huangarua zone was simulated for the 16-year transient model run and is shown in Figure F63. Seasonal abstraction (estimated abstraction using the methodology described in Gyopari and McAlister 2010c) only commenced in 2000/01 and peaked at about 2,300 m^3/day in 2005 subsequently dropping to about 1,700 m^3/day in 2007/08. The current consented abstraction is 9,300 m^3/day and therefore estimated use only comprises about 25% of the consented daily rate.

The model was also used to calculate the interaction between the Huangarua River and the groundwater environment (Figure F64). Because the calibration numerical model could not be verified, and information on the Huangarua River is very limited, there is a low degree of confidence in this prediction. Figure F64 suggests that in summer there is a net loss from the Huangarua River to groundwater of the order of 20,000 m^3/day (230 L/s). During winter there is a net river gain from groundwater discharge which is dependent upon rainfall recharge conditions and thereby highly variable from season to season.

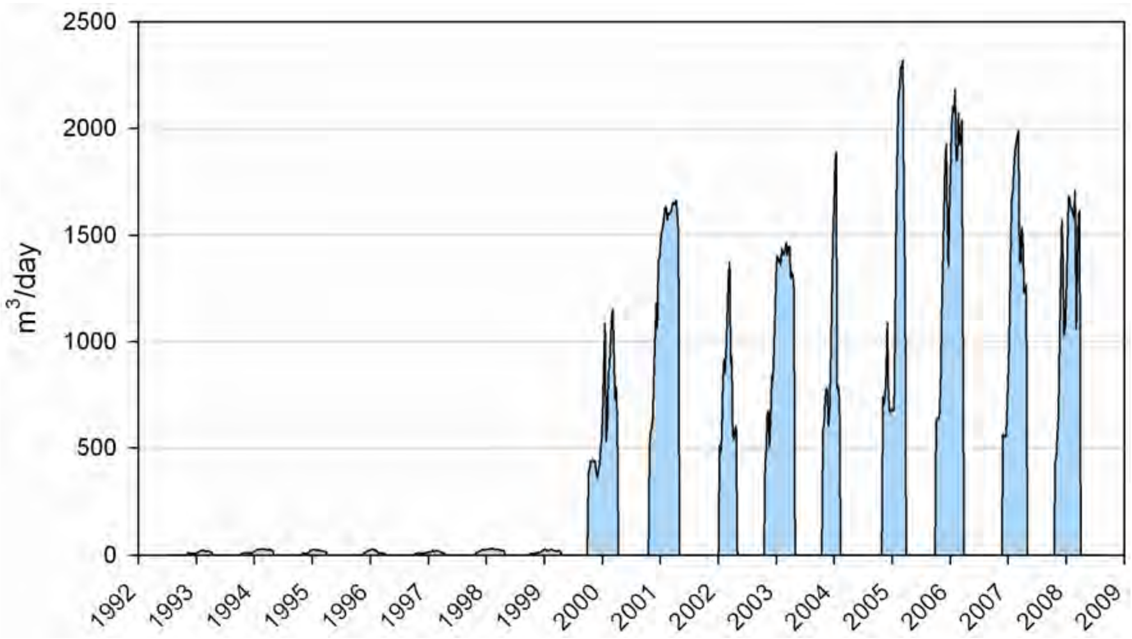

Figure F63: Simulated historic abstraction in the Huangarua zone from 12 bores. Vineyard irrigation abstraction only commenced in the 2000/01 summer.

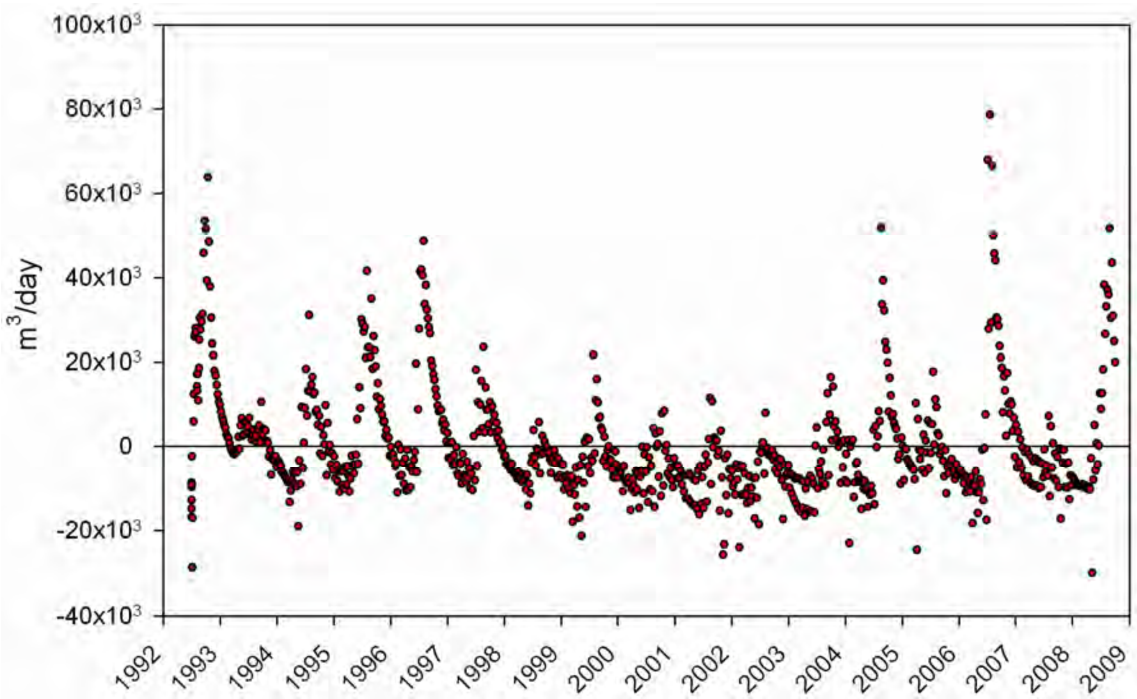

Figure F64: Simulated flux between the Huangarua River and groundwater expressed as the net flux out. A positive value means a net flux to surface water (i.e. river gain), and a negative value means a net flux to groundwater (i.e. river flow loss). In all years there is a summertime loss from the river to groundwater of up to about 20,000 m^3/day (230 L/s). During winter the flux is reversed.

F.10.6 Groundwater management options for the Huangarua water management zone

Groundwater-surface water interaction zones

- The shallow Q1 lower terrace aquifers of the Huangarua zone (delineated in Figure F61) are regarded to have a high degree of connection to the Huangarua River. It is recommended that this area be classified as Category A (direct hydraulic connection) to a depth of approximately 20 m and therefore managed as equivalent surface water takes from the Huangarua River.

- Bores lying outside the area classified as Category A should be designated Category B. Under this classification, groundwater takes in the Huangarua zone (outside Category A) would be assessed to determine the likely nature and magnitude of stream depletion effects and allocation apportioned between groundwater and surface water accordingly. Minimum flow controls may also be imposed on those takes that exhibit sufficiently direct hydraulic connection to the Huangarua River.

Groundwater allocation

- This zone is principally recharged by rainfall infiltration and losses from the Huangarua River. Since information on the hydrology of the Huangarua River is very limited, the numerical model and its predictions regarding the interaction between the river and groundwater cannot be verified. It is therefore recommended that allocation be referenced to rainfall recharge. The mean annual recharge has been calculated to be 3.22×10^6 m^3, and the lower quartile annual recharge is 1.36×10^6 m^3 or the period 1992 to 2008.

- The annual recharge rate for the Huangarua zone has a high standard deviation (see Figure F62). For the 1992 to 2008 period, the lower quartile annual recharge was 1.36×10^6 m^3/year or approximately 40% of the mean annual recharge. It is suggested that the annual allocation limit does not exceed 50% of the lower quartile annual recharge given that the aquifer is connected to the Huangarua River (nb higher allocation is recommended only in zones where there is no surface water connection).

- Allocation should be expressed as an annual maximum and a weekly maximum. The weekly maximum should be based upon a 180 day irrigation season.

Table F13 outlines potential allocation options for the Huangarua water management zone. Option 1 is recommended since the aquifers in this zone are connected to the surface water environment and an allocation of less than 50% of the lower quartile annual rainfall recharge is recommended. The Huangarua River is also known to experience severe algal blooms at low flow so it is prudent to limit any further depletion associated with groundwater abstraction.

Table F13: Allocation options for unregulated abstraction in the Huangarua water management zone

Options	Allocation reference *	Allocation (m^3/year x 10^6)	Allocation (m^3/day)
1	20% LSR (47% LQLSR)	0.644	3,600
2	30% LSR (71% LQLSR)	0.97	5,400
3	40% LSR (95% LQLSR)	1.29	7,200

*LSR = mean annual land surface recharge (rainfall recharge).; LQLSR = lower quartile annual land surface recharge.

F.11 Onoke water management zone

F.11.1 Overview

Delineation: The Onoke water management zone is located in a narrow section of the Wairarapa Valley between Lake Onoke at the coast and the southerly extent of the Lake basin (Lake zone). The zone is about 4 km wide and has a relatively shallow fill of late Quaternary alluvium which has a limited connection to the sea. The zone also incorporates the Turanganui and Tauanui river valleys (Figure F65).

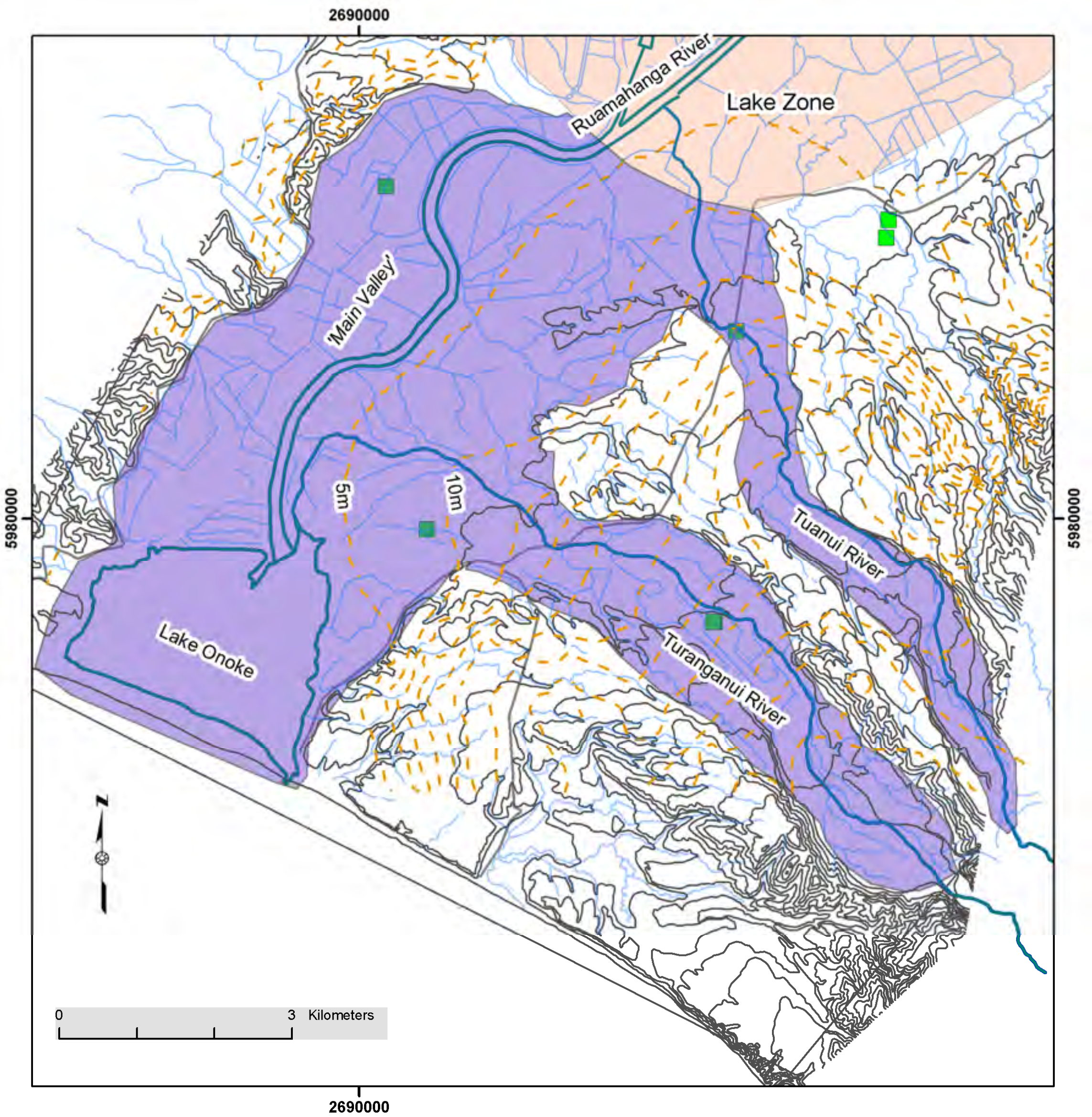

Figure F65: The Onoke water management zone defined by the recent alluvium of the Ruamahanga River valley and the Turanganui and Tauanui side-valleys. The map shows existing groundwater bores with consented abstraction (green squares) and groundwater flow contours (brown dashed lines in m amsl at 5 m intervals).

Area:	40.4 km^2.
Boundaries:	The northern and southern boundaries coincide with the edges of the recent alluvial plain marked by the contact between late Quaternary alluvium and older (early Quaternary and Tertiary) raised marine terrace sequences. The zone boundary also follows the edge of the recent alluvium in the Tauanui and Turanganui river valleys. The northern boundary with the Lake zone marks a rapid thinning of the aquifer sequence from the deep Lake basin. It also corresponds to an approximate groundwater flow divide created by side-valley recharge from the Tauanui and Turanganui rivers. The southern zone boundary follows the coastline.
Principal surface water systems:	Ruamahanga River, Turanganui River, Tauanui River, Lake Onoke and associated wetlands.
Aquifer sequences:	Confined aquifers 30 to 50 m depth (Q2 and older?) in the main valley. Unconfined-semi-confined alluvial fan deposits (Q1 and Q2?) associated with the Turanganui and Tauanui rivers.
Recharge:	Estimated average annual throughflow recharge to the main valley is 10.6 x 10^6 m^3 (29,040 m^3/day).
Existing RFP zones:	Lower Valley (sub-zones Onoke, Narrows, Turanganui, Tauanui).
Current allocation:	As at June 2010, there are currently six consented groundwater takes in the Onoke zone having a combined consented daily abstraction of 11,700 m^3/day. Only two of these are located in the main valley section where the total consented abstraction is 5,500 m^3/day. The Turanganui valley aquifer has an allocation of 4,800 m^3/day from two bores.

F.11.2 Hydrogeology summary

The Onoke zone is the southernmost zone in the Wairarapa Valley, extending from the end of Lake Wairarapa to the coast, incorporating Lake Onoke and the side valleys of the Turanganui and Tauanui rivers.

The Quaternary valley-fill sequence narrows considerably in the main valley (4 km wide) with prominent early Quaternary and Tertiary terraces bordering the zone to the north and south. The base of the aquifer system is tentatively estimated to be about 60 m at the northern end of the main valley, rising to about 10 m at the coast. The northern boundary corresponds to an area where intense tectonic activity begins to uplift the coastal area.

The coastal area has experienced significant uplift resulting in a condensed or truncated aquifer sequence. At the coast, the depth to 'basement' (Tertiary marine mudstone) is interpreted to be less than 10 m. This means there is very little coastal outflow of groundwater from the Wairarapa basin and therefore a very limited connection between aquifers in the Onoke/Narrows area and the sea.

A confined, presumably Q2 age, aquifer extends into this area from the Lake zone and is confined by overlying low permeability estuarine and marine silts. The southern side of the zone is more geologically complex. In this area lensoid gravel bodies associated with the fans of side valleys such as those of the Turanganui and Tauanui rivers intrude into the main valley. In addition, lower permeability older (early-mid) Quaternary deposits may occur at a considerably shallower depth on this side of the valley, sloping northwards towards the river thereby allowing the development of a channel of late Quaternary deposits (including the Q2 aquifer) along Ruamahanga River and to the north.

The alluvium occupying the Turanganui and Tauanui river valleys is of Q1 age but it is evident that an older semi-confined aquifer sequence occurs between 30 and 40 m in the Turanganui valley.

The principal recharge mechanism to the Onoke main valley confined aquifers is throughflow from the Tauanui and Turanganui side-valleys. Bed losses from these rivers flow through the permeable valley gravels which merge into the main valley-fill aquifers. Direct rainfall recharge is regarded as negligible in this zone, except in the side-valleys due the prevalence of artesian/confined conditions in the main valley. Figure F66 shows the simulated flow field for the Onoke zone (for July 2008) and the associated velocity vectors to demonstrate the recharge inputs from the side valleys and flow patterns in the main valley. Within the main valley, throughflow occurs mainly to the north into the Lake zone, and there is also minor flow to the sea along the coastal margin. The interaction between the Ruamahanga River (and Lake Onoke) and the underlying groundwater environment is poorly understood in this area due to the tidal nature of the river and lake. It seems probable that the river and lake receive vertical leakage from the confined aquifers in the valley.

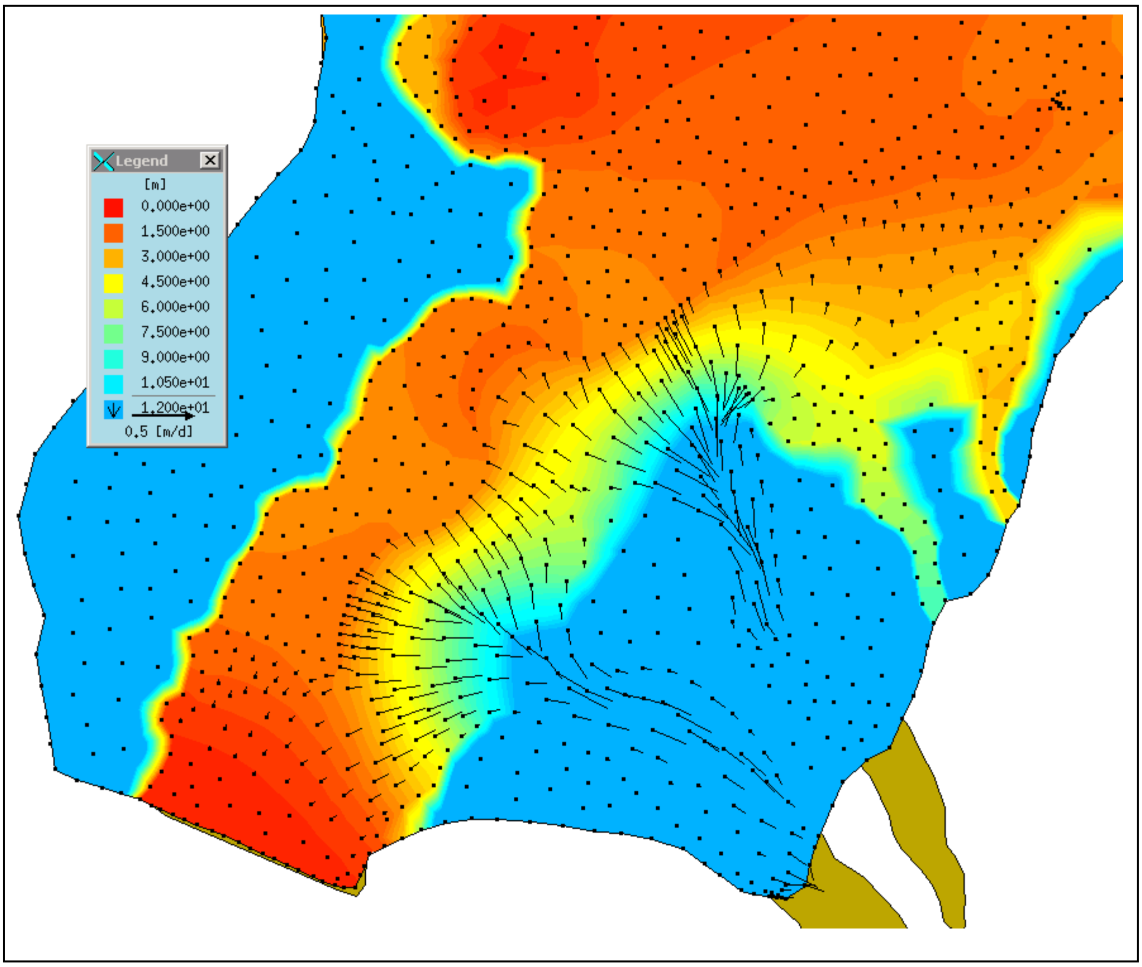

Figure F66: Simulated groundwater head pattern using FEFLOW in the Onoke and neighbouring Lake water management zones. The diagram also shows the flow vectors (length is proportional to flow velocity) demonstrating the input of recharge from the Tauanui and Turanganui rivers. The principal throughflow flux out of the zone is northwards into the Lake zone. There is only a very small throughflow to the sea (<200 m^3/day).

F.11.3 Hydrology

The Ruamahanga River is the principal drainage system in the Onoke zone. The river is tidal within the zone and is deeply incised (often artificially) within lower permeability silts and clays. As discussed above, there is probably limited interaction between the river and the groundwater environment in the Onoke zone, although the river channel may act to concentrate diffuse leakage occurring through the confining layer materials.

There is sparse information on the Tauanui and Turanganui rivers. Both are high gravel load semi-braided drainage systems. In their lower reaches both rivers frequently dry up during low-rainfall periods although sub-surface flows through adjacent alluvial gravels are likely to continue.

Lake Onoke is a 650 ha brackish lagoon at the mouth of the Ruamahanga River. It is separated from Palliser Bay by a 3 km long shingle spit which is breached by rising lake levels. The lake is generally tidal and can back up as far as the barrage gates on the Ruamahanga River under certain conditions. The lake is also inferred to receive seepage discharge from the underlying confined aquifers.

F.11.4 Zone management objectives

The principal objective of groundwater allocation in Onoke zone is to ensure the sustainable use of groundwater resources by having specific regard to the instream values of surface water systems and aquifer drawdowns in the confined main valley area.

Within the Onoke zone, only the Tauanui and Turanganui rivers have a direct connection to the groundwater environment and the protection of baseflow in these systems is therefore of primary importance.

Within the main valley section of the Onoke zone, the management objective is to ensure that allocation is sustainable and does not result in adverse drawdown effects on other users. Lake Onoke and the Ruamahanga River are not regarded to be sensitive to the effects of potentially reduced leakage from groundwater.

F.11.5 Numerical modelling

The numerical groundwater model for the Lower Valley catchment was used to assess the sustainability of current groundwater abstractions and to develop sustainable allocation options for the Onoke water management zone. Details of the model and its calibration are provided in Gyopari and McAlister (2010c). It should be noted that due to the limited availability of hydrological, groundwater monitoring and geological data, the uncertainty inherent in the model for the Onoke zone is relatively high.

<u>Zone water balance</u>

The numerical groundwater flow model was used to quantify the natural water balance for the Onoke zone by running the model for a period of 16 years (1992 to 2008) in the absence of abstraction. Of particular interest is the throughflow fluxes into and out of the main valley section of the zone.

The principal water balance components for the Onoke zone are throughflow from the Turanganui and Tauanui rivers, the throughflow out of the main valley section into the Lake zone and to the sea. These fluxes also encapsulate the recharge from the side valley rivers.

Figure F67 shows the simulated throughflows out of the two side valleys (Turanganui and Tauanui) and into the main valley section of the Onoke zone. The mean throughflow flux is 29,200 m^3/day (340 L/s).

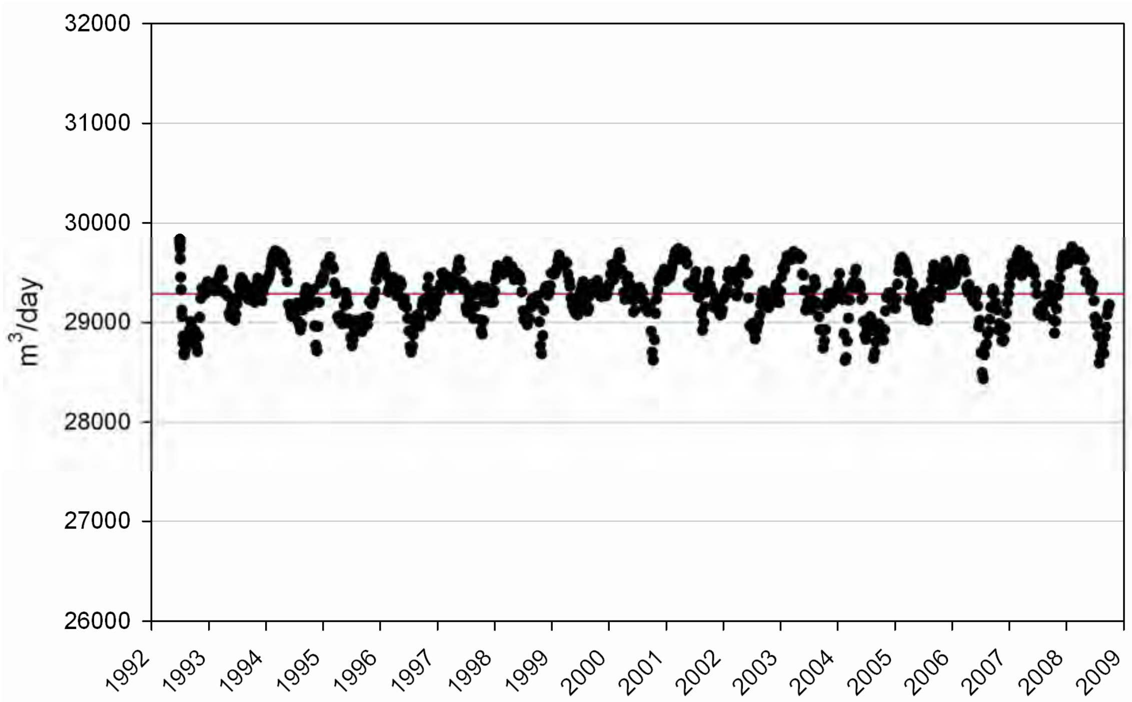

Figure F67: Simulated throughflow from the Turanganui and Tauanui rivers into the main valley section of the Onoke zone, 1992–2008 (no abstraction scenario). Mean daily throughflow is depicted by the red line.

Figure F68 shows the simulated throughflows out of the Onoke zone (represented as a negative flux) – northwards into the Lake zone and southwards offshore. The flow offshore is very small at 2 to 300 m^3/day whereas the discharge from the Onoke zone to the north into the Lake zone is about 12,500 m^3/day. The balance between the throughflow into the main valley (Figure F67) and out of the main valley (Figure F68) is about 16,000 m^3/day which is the simulated mean discharge to the Ruamahanga River and Lake Onoke (Figure F69).

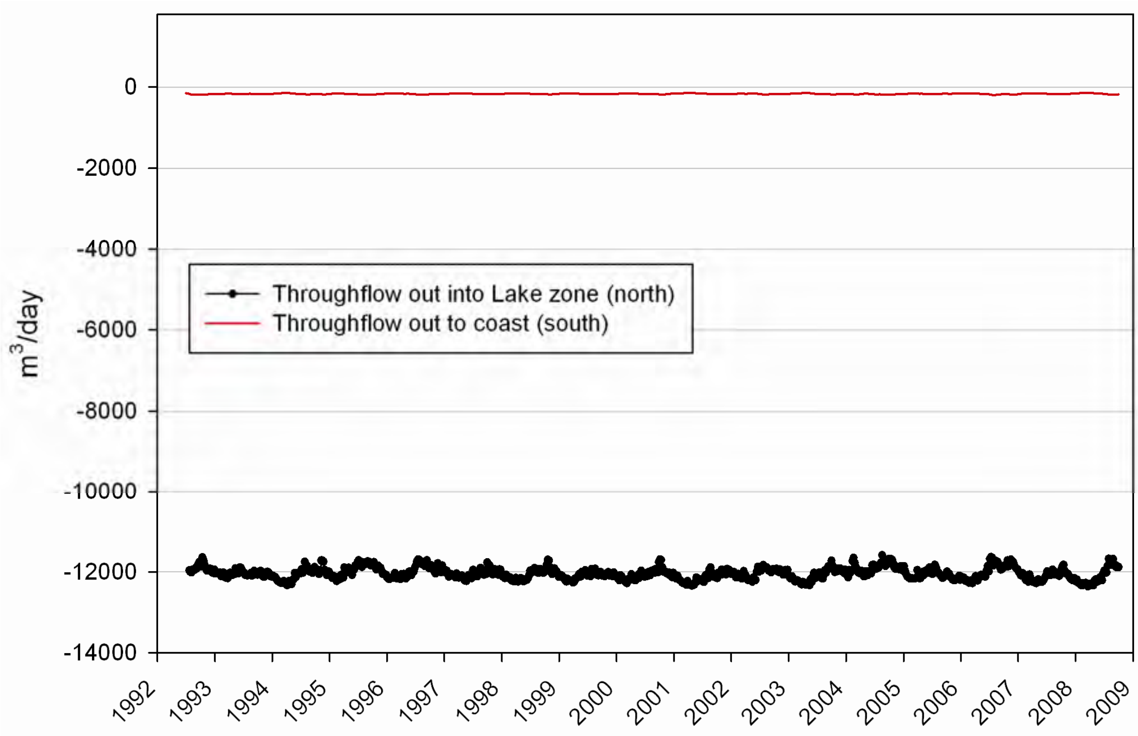

Figure F68: Simulated throughflow discharge from the main valley section of the Onoke zone – to the north into the Lake zone and to the south offshore

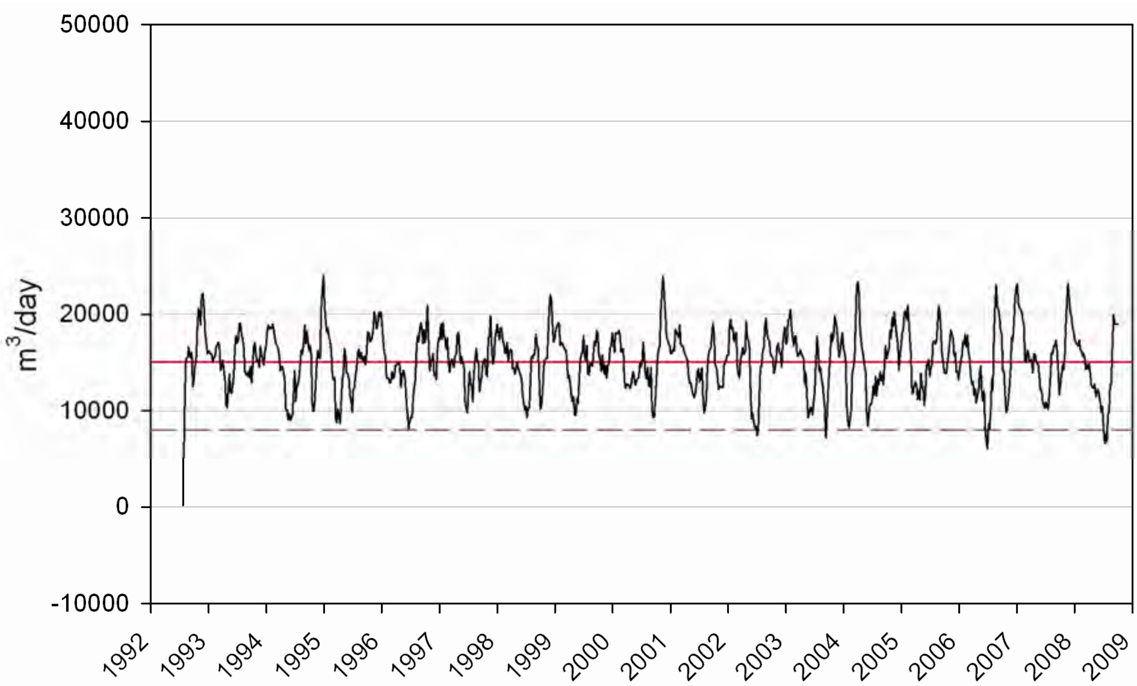

Figure F69: Simulated groundwater discharge to surface water (to the Ruamahanga River and Lake Onoke) in the main valley section of the Onoke zone for the period 1992–2008 (no abstraction scenario). Mean discharge is show by the red line (16,000 m^3/day), and the mean seasonal minima is shown by the dashed line (approximately 8,000 m^3/day).

F.11.6 Abstraction effects

The effects of historical abstraction between 1992 and 2008 on the throughflow dynamics of the Onoke zone were examined by comparing the simulated fluxes from the no-abstraction simulation with the abstraction scenario.

Figure F70 shows the changes in throughflows predicted by the model (positive fluxes are increases in throughflow into the Onoke zone, and negative fluxes are increases in throughflow out of the zone). Abstraction from the main valley section of the Onoke zone causes a small enhancement of throughflow from the side valleys (up to about 400 m^3/day). The abstraction scenario (which includes the effects of abstraction from the Lake zone aquifers) shows virtually no change in aquifer discharge at the coast.

Pumping from the Lake zone aquifers is also reflected in an increased throughflow rate northwards out of the Onoke zone into the Lake zone. The induced throughflow peaks at only 500 m^3/day during the 2007/08 irrigation season. Figure F70 suggests that the fluxes into and out of the Onoke zone are generally not significantly impacted by abstraction in the neighbouring Lake zone.

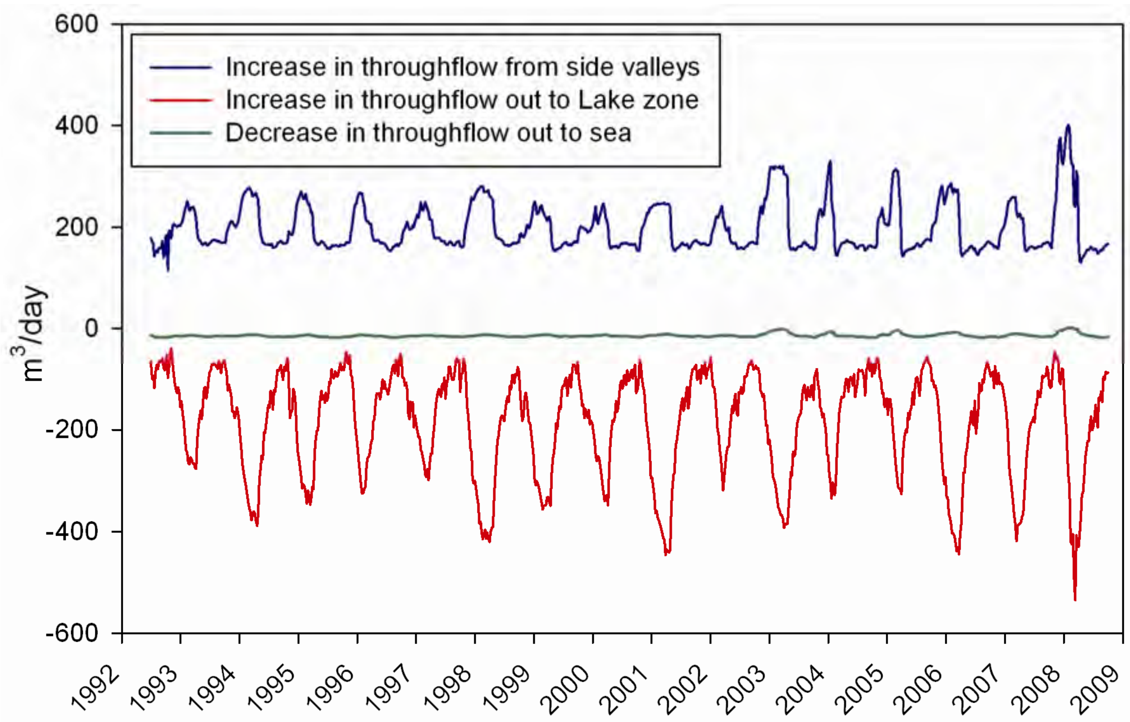

Figure F70: Simulated changes in the rate of natural groundwater throughflow into and out of the Onoke water management zone in response to current abstraction in the Lower Valley.

F.11.7 Groundwater management options for the Onoke water management zone

Groundwater-surface water interaction zones

- The Turanganui and Tauanui side valleys of the Onoke zone (to the point where they enter the main valley section) should have Category A status. This would enable active management of potential stream depletion effects resulting from abstraction from the high permeability Q1/Q2 gravels along the riparian margins of these rivers

Groundwater allocation

- The 'main vallley' section of the Onoke groundwater management zone should be designated Category C.

- The sustainable groundwater allocation for the main valley section of the Onoke zone should be referenced with regard to throughflow recharge from the side valleys (the principal recharge source). Allocation should also take into consideration groundwater discharge fluxes to the surface water environments (as predicted by the numerical model). Assuming that there is relatively little storage in the confined aquifers, allocation should be referenced to daily (rather than annual) flux rates. These are:

    - mean daily throughflow recharge 29,000 m^3 (see Figure F67).

    - mean daily surface water discharge 16,000 m^3

- Potentially, throughflow recharge will be affected by further development of the side valley aquifers. Therefore only a portion of the predicted throughflow recharge from the side valleys to the main valley section of the Onoke zone should be allocated. It is conservatively recommended that allocation should not exceed 30 to 40% of the throughflow recharge.

- The surface water discharge environments in the main valley section are regarded to be relatively insensitive to depletion effects (they are largely tidal systems), but it is important to ensure that vertical hydraulic gradients in the aquifer do not reverse due to excessive drawdowns. It is therefore recommended that the daily allocation rate does not exceed the predicted annual mean groundwater discharge rate and remains comfortably below it. This approximates the modelled minimum seasonal discharge rate (see Figure F69).

Suggested allocation options for the Onoke water management zone are presented in Table F14. Option 2 is recommended for the reasons discussed above.

Table F14: Allocation options for unregulated Category C takes in the Onoke zone. Annual allocation is based on 180 days of pumping.

Options	Allocation reference	Allocation (m^3/day)	Allocation (m^3/year x 10^6)	% of modelled surface water discharge
1	30% throughflow recharge	8,700	1.57	54
2	40% throughflow recharge	11,600	2.09	73

Appendix G: Hydraulic connectivity zonation

Interpreting the map

Management zones

Upper Ruamahanga — Zone name and boundary

Abstraction categories – spatial extent

Category A

Category B

Category C

Abstraction categories – depth extent

A —20 B —30 C

This example is for a bore located within a Category A spatial zone (e.g. like that in the Waingawa management zone in the map).

Bores drawing water from a depth of less than 20 m remain Category A, but if they are between 20 and 30 m they become Category B and Category C if they are deeper than 30 m.

See Figures 3.7 and 3.8 in Section 3.3 of the main report for further illustration of depth categories.

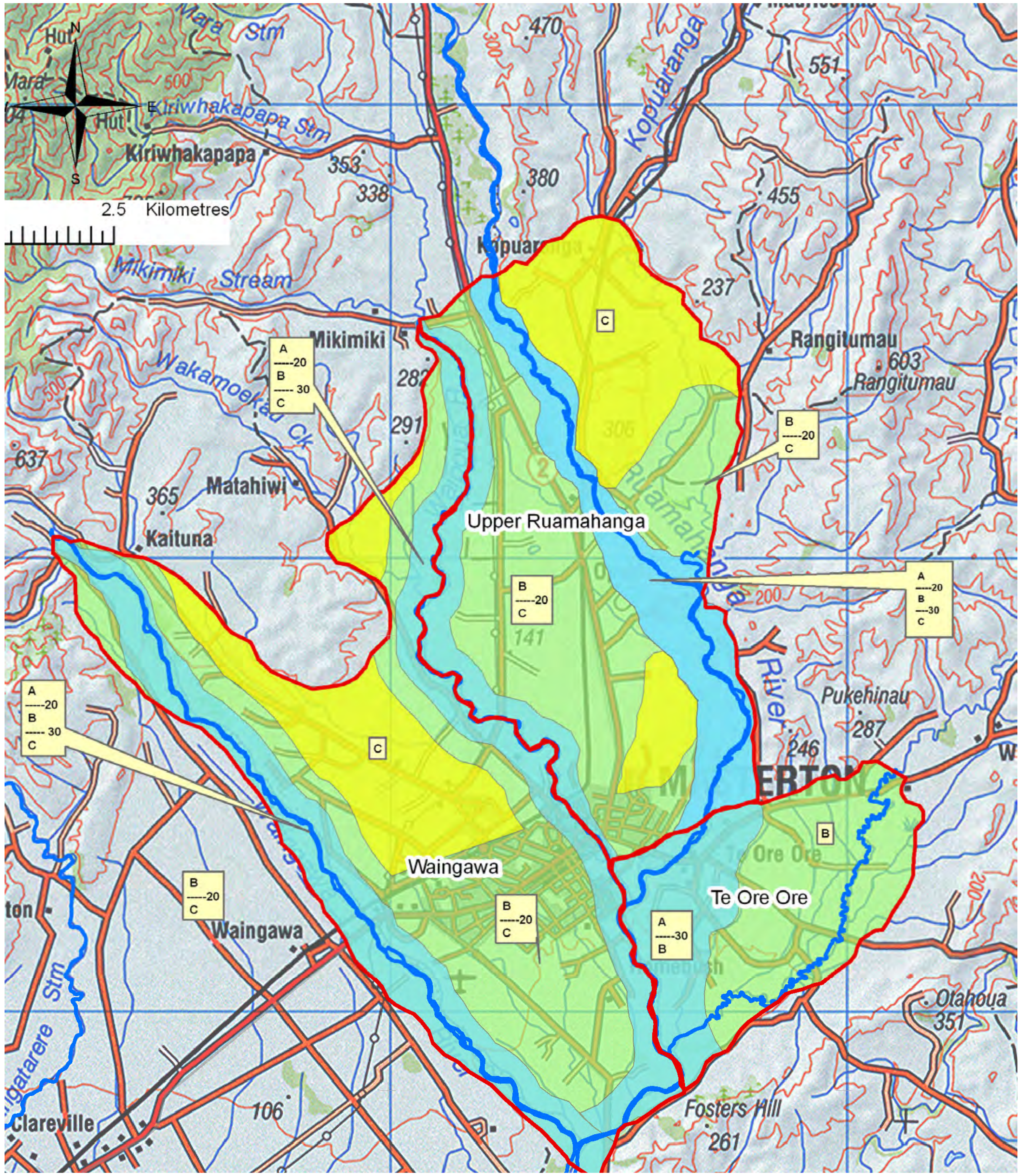

Figure G1: Geographical (spatial) and depth distribution of hydraulic connectivity categories across the Upper Valley

Interpreting the map

Management zones

Mangatarere — Zone name and boundary

Abstraction categories – spatial extent

Category A

Category B

Category C

Abstraction categories – depth extent

A —20 B —30 C

This example is for a bore located within a Category A spatial zone (e.g. like that in the Mangatarere management zone in the map).

Bores drawing water from a depth of less than 20 m remain Category A, but if they are between 20 and 30 m they become Category B and Category C if they are deeper than 30 m.

See Figures 3.7 and 3.8 in Section 3.3 of the main report for further illustration of depth categories.

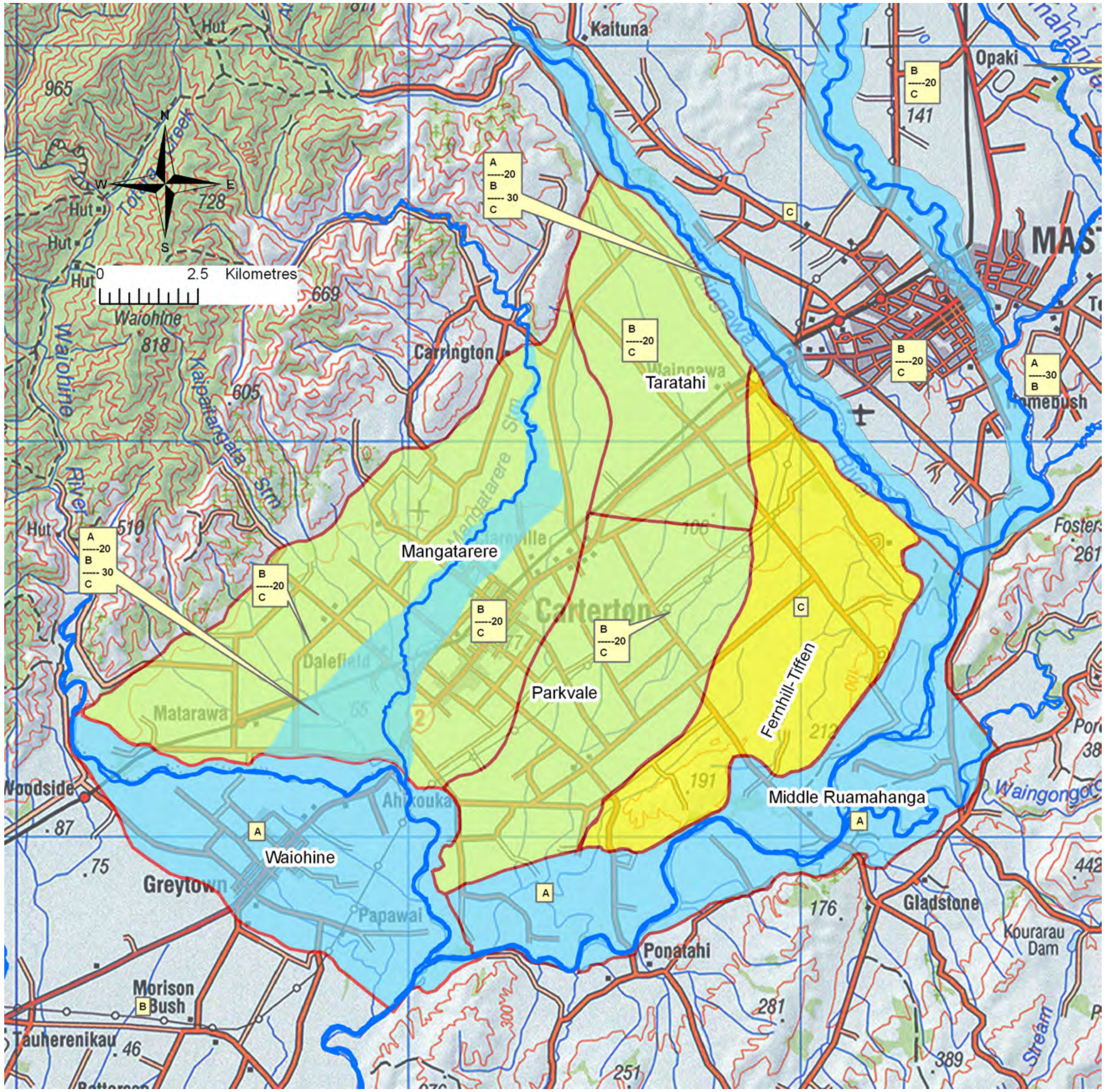

Figure G2: Geographical (spatial) and depth distribution of proposed hydraulic connectivity categories across the Middle Valley

Interpreting the map

Management zones

Tauherenikau — Zone name and boundary

Abstraction categories – spatial extent

Category A

Category B

Category C

Abstraction categories – depth extent

B
—15
C

This example is for a bore located within a Category B spatial zone (e.g. like that in the 'Lake' management zone in the map).

Bores drawing water from a depth of less than 15 m remain Category B, but if they are deeper than 15 m they become Category C.

See Figures 3.7 and 3.8 in Section 3.3 of the main report for further illustration of depth categories.

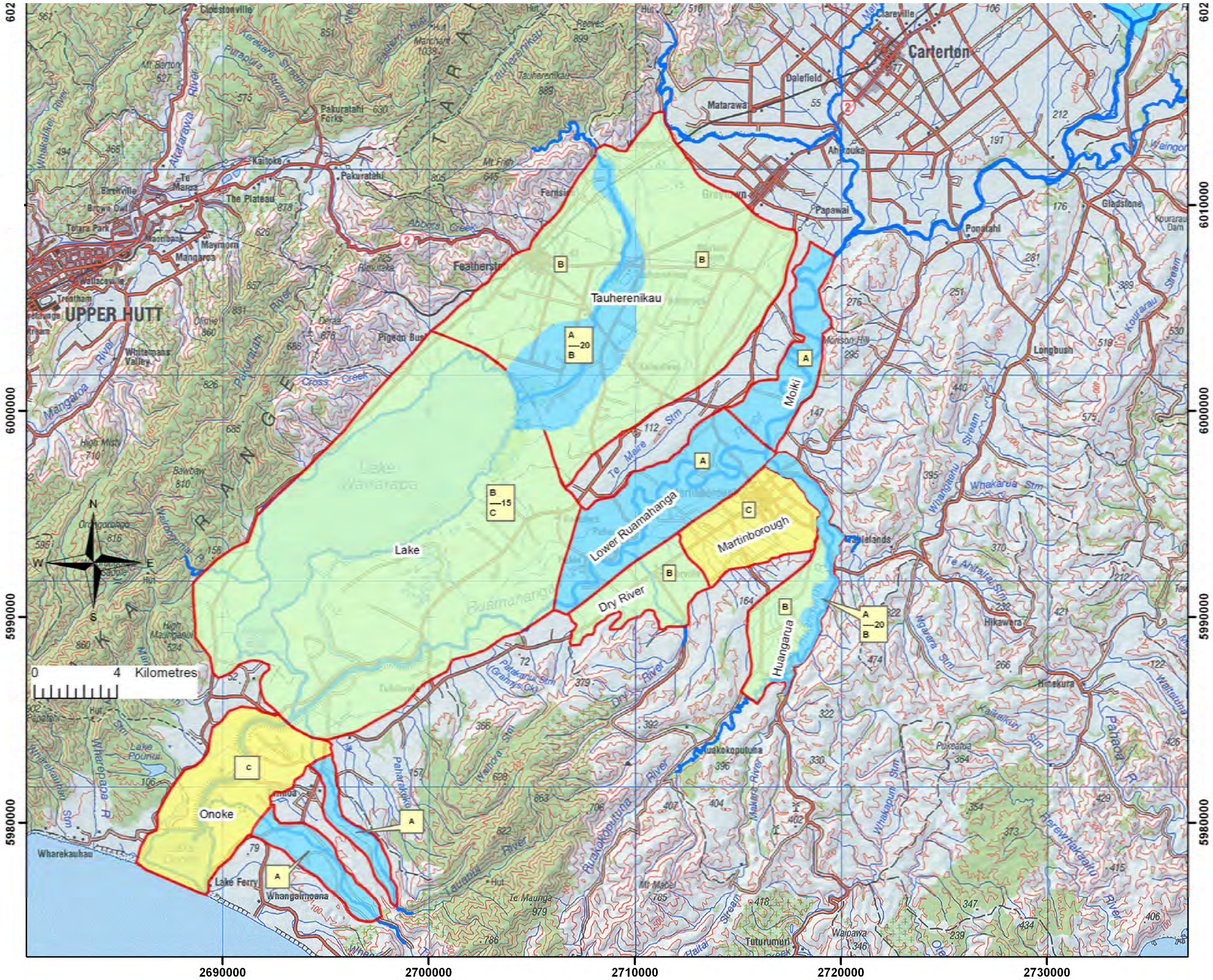

Figure G3: Geographical (spatial) and depth distribution of hydraulic connectivity categories in the Lower Valley

Appendix H: Uncertainty

H.1 Numerical model uncertainty

Development of the recommended groundwater allocation limits for the Wairarapa Valley contained in this report has relied upon numerical groundwater models (Gyopari and McAlister, 2010 a,b,c). Models are necessarily simplified representations of complex natural geological environments and are utilised to predict the system response to various stress scenarios, for example, variations in groundwater abstraction or climate conditions.

Because models must simulate a complex subsurface environment which has been characterised using relatively few measurements and simplified, they unavoidably have an inherent uncertainty and no model can be 100% accurate. However, by following a robust process both during the conceptualistion phase and during the calibration process, model uncertainty can be minimised and quantified.

Factors contributing to uncertainty in groundwater models include:

- Conceptual and geological framework uncertainty
- Model parameter uncertainty and calibration non-uniqueness
- Predictive uncertainty

These are discussed in further detail below.

H.1.1 Conceptual and geological framework uncertainty

All groundwater models are based on a conceptual model which is a simplified representation of a complex and heterogeneous geological environment. This understanding is then translated into a quantitative numerical model. Strong emphasis must therefore be placed on producing a sound conceptualisation of the groundwater system as a fundamental basis for numerical analysis.

The purpose, form and significance of a conceptual model is explained in the MDBC modelling guidelines (Middlemis 2001):

- Development of a valid conceptual model is the most important step in a computer modelling study.
- The conceptual model is a simplified representation of the essential features of the physical hydrogeological system and its hydrogeological behaviour, to an adequate degree of detail.
- Conceptual models are subject to simplifying assumptions which are required because a complete reconstruction of the field system is not feasible, and because there is rarely sufficient data to completely describe the system in comprehensive detail.
- The conceptualisation is developed using the principle of parsimony such that the model is as simple as possible while retaining sufficient

complexity to adequately represent the physical elements of the system and to reproduce system behaviour.

The conceptual hydrogeological model has been tailored to ensure it can adequately address the key issues faced in the management of the groundwater resources in the Wairarapa Valley. Specifically, these issues are:

- The sustainability of groundwater abstractions;
- The effects of groundwater abstractions on the surface water environment

H.1.2 Model parameter uncertainty and calibration non-uniqueness

The model calibration process seeks to optimise the fit between the model and actual observations (typically groundwater levels and water balance components) whilst remaining faithful to the conceptual framework and parameter measurements. In terms of the Wairarapa models, calibration to measured stream-aquifer fluxes has been a particular focus. Calibration is carried out by adjusting model input parameters (i.e. hydraulic conductivity, storage, recharge, river bed conductance) - but relatively sparse field data exist with which to define these parameters, many of which are estimated during the calibration process. Automated calibration procedures can greatly reduce the subjectivity of parameter estimation – this was undertaken for the Wairarapa models.

The problem of model non-uniqueness is inherent in all complex groundwater flow models and arises because a number of different parameter sets can produce the same model calibration – i.e. multiple calibrations are possible using different combinations of model inputs because certain parameters (such as recharge and transmissivity) are highly correlated. The matching of measured heads alone by a 'calibrated model' does not mean that the hydraulic properties used in the model are correct and that the model can be confidently used for predictive purposes.

The MDBC (Middlemis 2001) modelling guidelines suggest that the following methods should be conjunctively employed to reduce the non-uniqueness of a model:

- Calibrate the model using hydraulic conductivity (and other) parameters that are consistent with measured values. The range for various parameters is justifiably restricted.
- Calibrate the model to a range of hydrogeological conditions (a wide range of climate and induced stresses such as abstraction).
- When possible, calibrate the model using measured water balance fluxes (such as spring flows, river losses/gains) as calibration targets.

These recommendations were implemented in the Wairarapa models to minimise model non-uniqueness and parameter uncertainty.

H.1.3 Predictive uncertainty

Predictive uncertainty refers to the ability of a model to evaluate any particular hypothetical scenario, given the particular combination of parameters used to construct the model. Because all models are inherently uncertain, it follows that no model output should be reported as a *single* model result unless that it is accompanied by a due-diligence effort at estimating the associated expected uncertainty (Barnett et al 2012). To assess the uncertainty associated with key predictions which underpin the groundwater allocation framework for the Wairarapa Valley, quantification of uncertainty of the Middle Valley model has been undertaken (Moore 2011) and is summarised here. Since the three Wairarapa models have been constructed using essentially the same modelling and calibration methodologies and represent comparable hydrogeological environments, the results of the Middle Valley uncertainty analysis can be relatively confidently applied to the other models.

Uncertainty analysis provides quantification of the reliability of selected predictive simulations undertaken to provide knowledge that may guide groundwater allocation management decisions. This information conveys the relative confidence that a management decision will achieve its desired impact in respect of mitigation of surface water depletion and drawdown impacts. Estimates of reliability also allow a factor of safety to be incorporated into those management rules which are based on less reliable predictive simulations.

The uncertainty analysis was also designed to:

- Identify those parameters which are estimated more reliably and those where there remains significant uncertainty, even after the model calibration process.
- Identify those parameters which contribute most to the uncertainty of predictions and to identify areas of knowledge that would improve predictive reliability the most.
- Determine which data from the current monitoring network has the greatest impact in terms of reducing this uncertainty.
- Determine which predictions that are known most reliably and which are known least reliably.

A parameter identifiability analysis was used to indicate the certainty with which a parameter has been estimated. This analysis indicated that many of the model parameters remain uncertain even after the calibration process. This result is expected for groundwater models which must simulate a complex subsurface on the basis of relatively few measurements. It is this lack of parameter identifiability that forms the major contribution to the calculated prediction uncertainties.

The relative reliability of the selected critical model predictions varies between water management zones. In general, the calculated standard errors of the stream depletion predictions were within 10% of the calibrated estimate. Interzonal through-flow predictions had a similar magnitude of standard error. These calculated standard errors generally do not alter the recommended management approach for zones.

For each prediction, the increased knowledge of different parameter groups was compared and those groups where greater knowledge would enhance the prediction the greatest were identified. Increased knowledge of the hydraulic conductivity parameters was most commonly identified as the parameter group which supports predictive reliability the most. However in areas associated with high river recharge, the river bed conductance parameters were also identified as significant.

The study suggested that any further calibration efforts would benefit from the use of distributed parameter devices such as pilot points, which were adopted in the uncertainty analysis. This would allow more precise predictive simulations in future modelling work. The critical predictive simulations all focussed on the magnitude of impacts, however the lag between the stress and the experiencing of the impacts is also significant, and was a central component in assigning management approaches..

H.2 Other sources of uncertainty relating to the conjunctive water management framework

Aside from uncertainty inherent in the development and application of numerical models, other sources of uncertainty relating to the conjunctive water management framework include:

- **Geological heterogeneity.** Uncertainty in the geological environment undoubtedly contributes an element of uncertainty to the boundaries between the various hydraulic connection categories (A-C). However, due to the structure of the conjunctive water management framework, such uncertainties are not considered to be a major issue as the Category B classification is applied to those areas where the exact nature of groundwater/surface water interaction is uncertain. This uncertainty is (at least partially) resolved by a requirement for hydrogeological investigations to be undertaken to support any consent applications in such areas.

- **Modelled water use.** The scenario modelling undertaken to assumes that water use occurs across an entire 180-day irrigation season which, although possible under existing resource consent conditions, is typically in excess of the duration of actual water use. Since surface water depletion is often dependent on the duration of abstraction, this assumption is considered to provide a conservative assessment of likely effects on surface water (i.e. provide an overestimate of the effect on surface water). However, this effect is not considered to be significant in most cases since a modelled depletion effect close to the seasonal maximum was often reached well before 180 days (typically the depletion effect would increase rapidly over the first 100 days and then plateau off towards 180 days); this indicates choosing a shorter irrigation season would have little impact on the allocation recommendations. In addition to the duration of abstraction, there is some uncertainty relating to how much water was actually abstracted compared with how much has been allocated on paper (in the absence of full length pumping records for all groundwater abstractions). However, modelling work has sought to reduce this uncertainty as much as possible by relying on bore record surveys in several catchments to apply a correction factor to consented pumping rates.

- **River and stream flow statistics.** Recommended groundwater allocation limits in many parts of the Wairarapa Valley are based on a baseflow depletion effect as a percentage of mean annual low flow (MALF). Due to the error inherent in flow measurements and the process of naturalising flows, such flow statistics always contain an element of uncertainty. It is noted that MALF estimates used in the report do not attempt to naturalise flows for all baseflow depletion resulting from existing groundwater abstraction (while some riparian/Category A takes are accounted for, no Category B takes are). It is estimated that natural MALF may have been underestimated by up to 10%, but often by much less than this.

- **Climatic variability.** The assessment of likely effects of future pumping scenarios assumes climate stationarity (i.e. the range of future climate variability is similar to that occurring over the period of historical record used for the allocation assessment). The period of focus for the Wairarapa Valley groundwater modelling (1992-2006) incorporated short term climate phases of both increasing mean annual rainfall (eg, 1990s) and decreasing rainfall (late 1990s until about 2004) and bridged a transition period between La nina-dominated and neutral climate phases (Keenan et al 2012). There is no indication that the assessment period was heavily biased towards either ‘dry’ or ‘wet’ conditions. Neveretheless, climate change projections for the Wairarapa indicate reasonably significant decreases in winter and spring rainfall in the long term (Keenan et al 2012) that could be consequential with respect to groundwater allocation policy. The only meaningful way to address limitations associated with climate stationarity and to adjust as climate change projections firm up is to conduct periodic reviews and update the technical information underpinning minimum flow and allocation limits.

- **Irrigation returns.** Modelling undertaken does not explicitly account for irrigation returns to river flow. While irrigation undoubtedly increases seasonal land surface recharge, provided irrigation is undertaken in an efficient manner, any such returns occur following the irrigation season (i.e. elevated soil moisture from irrigation results in recharge occurring earlier in the autumn/winter months than occurs under dryland conditions), and therefore this effect typically occurs after the critical low flow periods which are the focus for conjunctive water management. In terms of calculating MALF, since irrigation returns are not accounted for, the MALF would tend to be overestimated in areas where irrigation returns are significant (i.e. Category A zones particularly along the Ruamahanga River). A fuller discussion of irrigation returns is provided in Appendix H in response to peer review comment. In summary, the lack of explicit account for potential irrigation returns is not thought to introduce the scale of error or uncertainty into the allocation recommendations that might justify alterations.

- **Connectivity zone definition.** In terms of the hydraulic connectivity zonation, potential uncertainty in local hydrogeological conditions is recognised by a requirement to undertake specific hydrogeological investigations to characterise local groundwater/surface water interaction in Category B areas. In contrast, the relatively high certainty regarding the potential nature of groundwater/surface water interaction is built into the differing management approaches for Category A and Category C areas.

H.3 Summary

Collectively, the factors outlined in the preceding sections contribute to uncertainty associated with application of the conjunctive water management framework and calculated groundwater allocation volumes. However, on balance, it is considered that this uncertainty does not significantly detract from the validity of the approach or the robustness of the recommendations. Model predictive uncertainty in terms of simulated surface water depletions resulting from groundwater abstraction has been quantified at +/- 10% which provides a good degree of confidence in the calculated sustainable allocation volumes for water management zones.

Recommended groundwater allocation limits are therefore not likely to be overly conservative given the inherent uncertainties both in characterising the groundwater environment and in the modelling process.

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